UNITED STATES AIR FORCE

SUMMER RESEARCH PROGRAM -- 1999

SUMMER RESEARCH EXTENSION PROGRAM FINAL REPORTS

VOLUME 1

PROGRAM MANAGEMENT REPORT
ARMSTRONG LABORATORY

RESEARCH & DEVELOPMENT LABORATORIES

5800 Uplander Way

Culver City, CA 90230-6608

Program Director, RDL
Gary Moore

Program Manager, AFOSR
Colonel Jan Cerveny

Program Manager, RDL
Scott Licoscos

Program Administrator, RDL
Johnetta Thompson

Program Administrator, RDL
Rebecca Kelly-Clemmons

20010319 026

Submitted to:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Bolling Air Force Base

Washington, D.C.

December 1999

PREFACE

This volume is part of a four-volume set that summarizes the research of participants in the 1999 AFOSR Summer Research Extension Program (SREP). The current volume, Volume 1 of 4, presents the final reports of SREP participants at Armstrong Laboratory.

Reports presented in this volume are arranged alphabetically by author and are numbered consecutively -- e.g., 1-1, 1-2, 1-3; 2-1, 2-2, 2-3, with each series of reports preceded by a 35 page management summary. Reports in the four-volume set are organized as follows:

VOLUME	TITLE
1	Armstrong Research Laboratory
2	Phillips Research Laboratory
3	Rome Research Laboratory
4	Wright Research Laboratory

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Gary Moore

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5800 Uplander Way
Culver City, CA 90230-6608

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13. ABSTRACT *(Maximum 200 words)*
The United States Air Force Summer Research Program (SRP) is designed to introduce university, college, and technical institute faculty members to Air Force research. This is accomplished by the faculty members, graduate students, and high school students being selected on a nationally advertised competitive basis during the summer intersession period to perform research at Air Force Research Laboratory (AFRL) Technical Directorates and Air Force Air Logistics Centers (ALC). AFOSR also offers its research associates (faculty only) an opportunity, under the Summer Research Extension Program (SREP), to continue their AFOSR-sponsored research at their home institutions through the award of research grants. This volume consists of the SREP program background, management information, statistics, a listing of the participants, and the technical report for each participant of the SREP working at the AF Armstrong Laboratory.

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17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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C - Contract	**PR** - Project
G - Grant	**TA** - Task
PE - Program Element	**WU** - Work Unit Accession No.

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Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

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DOE - See authorities.
NASA - See Handbook NHB 2200.2.
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DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
Leave blank.
NASA - Leave blank.
NTIS -

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Block 15. Number of Pages. Enter the total number of pages.

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Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

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Phillips Research Laboratory

Volume 2

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Wright Research Laboratory

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Wright Research Laboratory

Volume 4, continued

1999 SUMMER RESEARCH EXTENSION PROGRAM (SREP) MANAGEMENT REPORT

1.0 BACKGROUND

Under the provisions of Air Force Office of Scientific Research (AFOSR) contract F49620-90-C-0076, September 1990, Research & Development Laboratories (RDL), an 8(a) contractor in Culver City, CA, manages AFOSR's Summer Research Program. This report is issued in partial fulfillment of that contract (CLIN 0003AC).

The Summer Research Extension Program (SREP) is one of four programs AFOSR manages under the Summer Research Program. The Summer Faculty Research Program (SFRP) and the Graduate Student Research Program (GSRP) place college-level research associates in Air Force research laboratories around the United States for 8 to 12 weeks of research with Air Force scientists. The High School Apprenticeship Program (HSAP) is the fourth element of the Summer Research Program, allowing promising mathematics and science students to spend two months of their summer vacations working at Air Force laboratories within commuting distance from their homes.

SFRP associates and exceptional GSRP associates are encouraged, at the end of their summer tours, to write proposals to extend their summer research during the following calendar year at their home institutions. AFOSR provides funds adequate to pay for SREP subcontracts. In addition, AFOSR has traditionally provided further funding, when available, to pay for additional SREP proposals, including those submitted by associates from Historically Black Colleges and Universities (HBCUs) and Minority Institutions (MIs). Finally, laboratories may transfer internal funds to AFOSR to fund additional SREPs. Ultimately the laboratories inform RDL of their SREP choices, RDL gets AFOSR approval, and RDL forwards a subcontract to the institution where the SREP associate is employed. The subcontract (see Appendix 1 for a sample) cites the SREP associate as the principal investigator and requires submission of a report at the end of the subcontract period.

Institutions are encouraged to share costs of the SREP research, and many do so. The most common cost-sharing arrangement is reduction in the overhead, fringes, or administrative charges institutions would normally add on to the principal investigator's or research associate's labor. Some institutions also provide other support (e.g., computer run time, administrative assistance, facilities and equipment or research assistants) at reduced or no cost.

When RDL receives the signed subcontract, we fund the effort initially by providing 90% of the subcontract amount to the institution (normally $18,000 for a $20,000 SREP). When we receive the end-of-research report, we evaluate it administratively and send a copy to the laboratory for a technical evaluation. When the laboratory notifies us the SREP report is acceptable, we release the remaining funds to the institution.

2.0 THE 1999 SREP PROGRAM

SELECTION DATA: A total of 381 faculty members (SFRP Associates) and 130 graduate students (GSRP associates) applied to participate in the 1998 Summer Research Program. From these applicants 85 SFRPs and 40 GSRPs were selected. The education level of those selected was as follows:

1998 SRP Associates, by Degree			
SFRP		GSRP	
PHD	MS	MS	BS
83	1	3	19

Of the participants in the 1998 Summer Research Program 65 percent of SFRPs and 20 percent of GSRPs submitted proposals for the SREP. Fifty-four proposals from SFRPs and eleven from GSRPs were selected for funding, which equates to a selection rate of 65% of the SFRP proposals and of 20% for GSRP proposals.

1999 SREP: Proposals Submitted vs. Proposals Selected			
	Summer 1998 Participants	Submitted SREP Proposals	SREPs Funded
SFRP	85	54	34
GSRP	40	11	2
TOTAL	125	65	36

The funding was provided as follows:

Contractual slots funded by AFOSR	36
Laboratory funded	0
Total	36

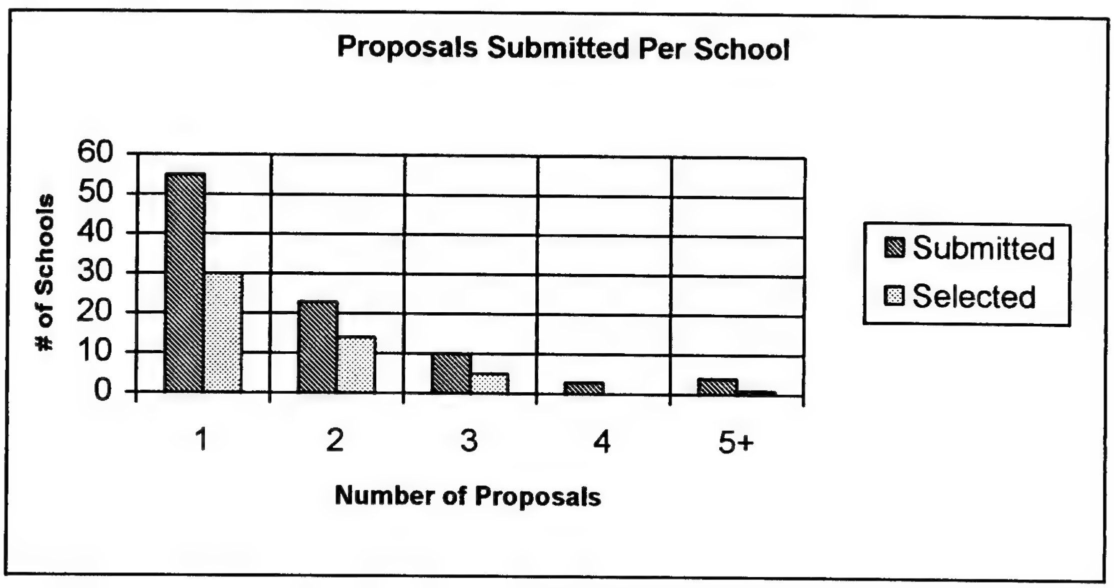
Four HBCU/MI associates from the 1998 summer program submitted SREP proposals; four were selected (none were lab-funded; all were funded by additional AFOSR funds).

Proposals Submitted and Selected, by Laboratory		
	Applied	Selected
Armstrong Research Site	15	3
Air Logistic Centers	1	0
Arnold Engineering Development Center	1	0
Phillips Research Site	10	8
Rome Research Site	12	7
Wilford Hall Medical Center	1	0
Wright Research Site	25	18
TOTAL	65	36

The 212 1998 Summer Research Program participants represented 60 institutions.

Institutions Represented on the 1998 SRP and 1999 SREP		
Number of schools Represented in the Summer 98 Program	Number of schools represented in submitted proposals	Number of schools represented in Funded Proposals
60	36	29

Thirty schools had more than one participant submitting proposals.



The selection rate for the 60 schools submitting 1 proposal (68%) was better than those submitting 2 proposals (61%), 3 proposals (50%), 4 proposals (0%) or 5+ proposals (25%). The 4 schools that submitted 5+ proposals accounted for 30 (15%) of the 65 proposals submitted.

Of the 65 proposals submitted, 35 offered institution cost sharing. Of the funded proposals which offered cost sharing, the minimum cost share was $1274.00, the maximum was $38,000.00 with an average cost share of $12,307.86.

Proposals and Institution Cost Sharing		
	Proposals Submitted	Proposals Funded
With cost sharing	35	30
Without cost sharing	30	6
Total	65	36

The SREP participants were residents of 31 different states. Number of states represented at each laboratory were:

States Represented, by Proposals Submitted/Selected per Laboratory		
	Proposals Submitted	Proposals Funded
Armstrong Research Laboratory	15	3
Air Logistic Centers	1	0
Arnold Engineering Development Center	1	0
Phillips Research Laboratory	10	8
Rome Research Laboratory	12	7
Wilford Hall Medical Center	1	0
Wright Research Laboratory	25	18

Six of the 1999 SREP Principal Investigators also participated in the 1998 SREP.

ADMINISTRATIVE EVALUATION: The administrative quality of the SREP associates' final reports was satisfactory. Most complied with the formatting and other instructions provided to them by RDL. Thirty-six final reports have been received and are included in this report. The subcontracts were funded by $897,309.00 of Air Force money. Institution cost sharing totaled $356,928.00.

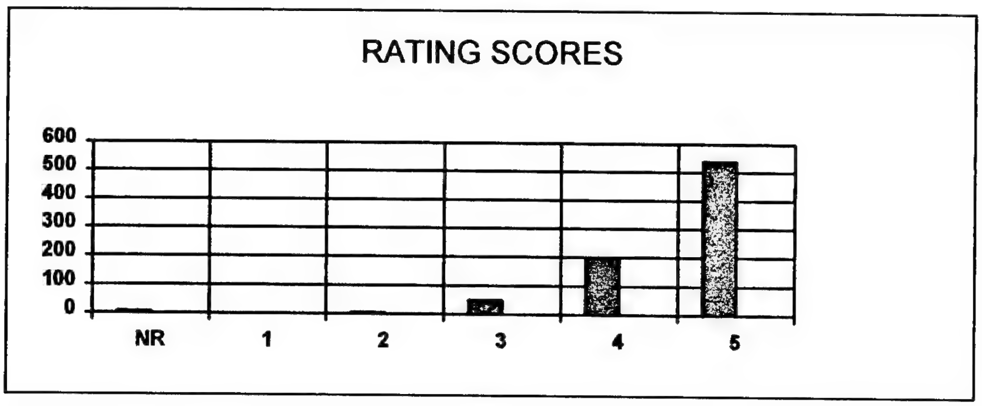
TECHNICAL EVALUATION: The form used for the technical evaluation is provided as Appendix 2. Thirty-two evaluation reports were received. Participants by laboratory versus evaluations submitted is shown below:

	Participants	Evaluations	Percent
Armstrong Laboratory	3	2	95.2
Phillips Laboratory	8	8	100
Rome Laboratory	7	7	100
Wright Laboratory	18	15	91.9
Total	36	32	95.0

Notes:

1: Research on four of the final reports was incomplete as of press time so there aren't any technical evaluations on them to process, yet. Percent complete is based upon 20/21=95.2%

PROGRAM EVALUATION: Each laboratory focal point evaluated ten areas (see Appendix 2) with a rating from one (lowest) to five (highest). The distribution of ratings was as follows:

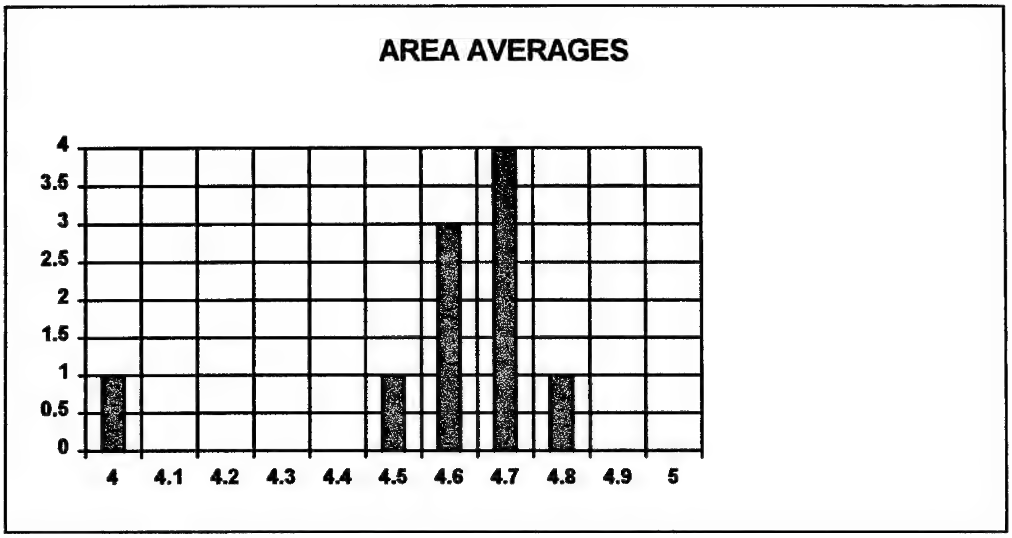


Rating	Not Rated	1	2	3	4	5
# Responses	7	1	7	62 (6%)	226 (25%)	617 (67%)

The 8 low ratings (one 1 and seven 2's) were for question 5 (one 2) "The USAF should continue to pursue the research in this SREP report" and question 10 (one 1 and six 2's) "The one-year period for complete SREP research is about right", in addition over 30% of the threes (20 of 62) were for question ten. The average rating by question was:

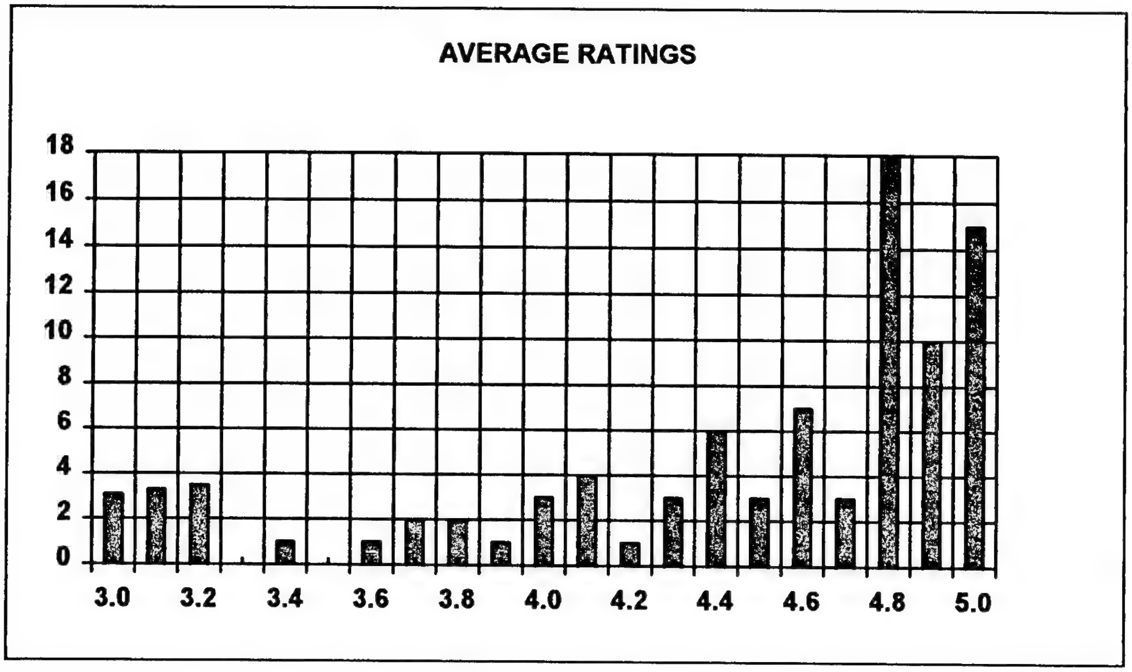
Question	1	2	3	4	5	6	7	8	9	10
Average	4.6	4.6	4.7	4.7	4.6	4.7	4.8	4.5	4.6	4.0

The distribution of the averages was:



Area 10 "the one-year period for complete SREP research is about right" had the lowest average rating (4.1). The overall average across all factors was 4.6 with a small sample standard deviation of 0.2. The average rating for area 10 (4.1) is approximately three sigma lower than the overall average (4.6) indicating that a significant number of the evaluators feel that a period of other than one year should be available for complete SREP research.

The average ratings ranged from 3.4 to 5.0. The overall average for those reports that were evaluated was 4.6. Since the distribution of the ratings is not a normal distribution the average of 4.6 is misleading. In fact over half of the reports received an average rating of 4.8 or higher. The distribution of the average report ratings is as shown:



It is clear from the high ratings that the laboratories place a high value on AFOSR's Summer Research Extension Programs.

3.0 SUBCONTRACTS SUMMARY

Table 1 provides a summary of the SREP subcontracts. The individual reports are published in volumes as shown:

Laboratory	Volume
Armstrong Research Laboratory	1
Phillips Research Laboratory	2
Rome Research Laboratory	3
Wright Research Laboratory	4

SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period	Contract Amount	Univ. Cost Share
Graetz , Kenneth Department of Psychology University of Dayton, Dayton, OH	PhD 99-0803	AL/CF Conflict resolution in distributed Meetingl: Using Collaboration Technology to	01/01/99 12/31/99	$24983.00	$0.00
Kannan , Nandini Statistics Univ of Texas at San Antonio, San Antonio, TX	PhD 99-0804	AL/CF Altitude decompression Sickness: Modeling and Prediction	01/01/98 12/31/98	$22492.00	$4478.00
Ramesh , Ramaswamy Magement Science/Systems Research Foundation of SUNY, Buffalo, NY	PhD 99-0802	AL/CF Modeling and Analsis of DMT Systems: Training Effectiveness, Costs, Resource Ma	01/01/99 12/31/99	$24979.00	$0.00
Le , Vanessa Biochemistry Univ of Texas at Austin, Austin, TX	BS 99-0805	AL/CF a Study on Stress-Induced Alterations In Blood-Brain Barrier Permeability to Pyr	01/01/98 12/31/98	$25000.00	$0.00
Gill , Gurnam EE Naval Postgraduate School, Monterey, CA	PhD 99-0834	PL/VT Adaptive signal Processing and its Applications in Space based Radar	01/01/99 12/31/99	$25000.00	$0.00
Hinde , Robert Physical Chemistry Univ of Tennessee, Knoxville, TN	PhD 99-0801	WL/PO Dopant-Induced Infrafed Activity in Solid Hydrogen An AB Initio and Quantum Mont	01/01/98 12/31/98	$25000.00	$3976.00
Jeffs , Brian Electrical Engineering Brigham Young University, Provo, UT	PhD 99-0828	PL/LI Algebraic Methods for Improved blimd Restoration of Adaptive Optics Images of Sp	01/01/98 12/31/98	$25000.00	$19177.00
Leo , Donald Mechanical & Aerospace Virginia Tech, Blacksburg, VA	PhD 99-0835	PL/VT Self-Sensing Acoustic Sources For Interior Noise Control in Payload Fairings	01/01/99 12/31/99	$24999.00	$7416.00
Lodhi , M. Arfin Nuclear Physics Texas Tech University, Lubbock, TX	PhD 99-0832	PL/VT Investigatioin into Time-Dependent Power Losses from AMTEC Components	01/01/99 12/31/99	$25000.00	$0.00
McHugh , John Applied Mechanics University of New Hampshire, Durham, NH	PhD 99-0833	PL/VT Atmospheric Gravity Waves Near The Tropopause	01/01/99 12/13/99	$25000.00	$7000.00
Steinberg , Stanly Mathematics University of New Mexico, Albuquerque, NM	PhD 99-0829	PL/LI Lie-Algebraic Representations of Product Integrals of Variable Matrices	01/01/99 12/31/99	$25000.00	$0.00
Stephens II , Kenneth University of North Texas, Denton, TX	MA 99-0830	PL/LI Simulation of a Magnetized Target Fusion Concept Using MACH2	01/01/99 12/31/99	$25000.00	$16764.00
Arvas , Ercument Electrical Engineering Syracuse University, Syracuse, NY	PhD 99-0808	WL/AA Realization of Low Noise MMIC Amplifier as a Microwave-to-Optics Link for Radar	01/01/99 12/31/99	$25000.00	$13000.00
Gopalan , Kaliappan Electrical Engineering Purdue Research Foundation, West Lafayette, IN	PhD 99-0814	RL/IR Detection of Acoustic Correlates of Stress from Modulation Characteristics	01/01/99 12/31/99	$25000.00	$38168.00

SREP SUB-CONTRACT DATA

Report Author / Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount	Univ. Cost Share
Hung , Donald Electrical Engineering Washington State University, Richland, WA	PhD 99-0812	RL/IR	01/01/99	12/31/99	$25000.00	$23008.00
		An Investigation on Accelerating the Ray-Tracing Compputations				
Lutoborski , Adam Applied Mathematics Syracuse University, Syracuse, NY	PhD 99-0811	RL/IR	01/01/99	12/31/99	$25000.00	$1274.00
		Transform Methods for Watermarking Digital Images				
Panda , Brajendra Computer Science University of North Dakota, Grand Forks, ND	PhD 99-0810	RL/IR	01/01/98	12/31/98	$24942.00	$2600.00
		Implementation of Petri Nets Based Multi-source Attack Detection Model				
Potter , Jerry Computer Science Kent State University, Kent, OH	PhD 99-0809	RL/IR	01/01/99	12/31/99	$25000.00	$52767.00
		Algorithms for Data Intensive Knowledge Discovery				
Upadhyaya , Shambhu Elec & Comp Engineering SUNY Buffalo, Buffalo, NY	PhD 99-0813	RL/IR	01/01/98	12/31/98	$25000.00	$6430.00
		a Distrubuted concurrent Intrusion Detection And recovery Scheme based on Assert				
Ahmed , Farid Electrical engineering Penn State Uni-Erie, Erie, PA	PhD 99-0806	WL/AA	10/10/98	12/31/98	$25000.00	$2396.00
		Image Quality Assessment for ATR Applications Using Multiresolutional Informatio				
Belfield , Kevin Chemistry University of Central Florida, Orlando, FL	PhD 99-0816	WL/ML	01/01/99	12/31/99	$25000.00	$5765.00
		Synthesis of New Two-Photon Absorbing Dyes, Monomers and Polymers				
Buck , Gregory Mechanical Engineering S Dakota School of Mines/Tech, Rapid City, SD	PhD 99-0818	WL/FI	01/01/99	12/31/99	$25000.00	$7639.00
		Acoustic Disturbance Source Modeling and Development for Hypersonic Receptivity				
Gilcrease , Patrick Chemical Engineering University of Wyoming, Laramie, WY	PhD 99-0815	WL/ML	01/01/99	12/31/99	$25000.00	$28010.00
		Biocatalysis of Biphenyl and Diphenylacetylene in an Aqueous-Organic Biphasic Re				
Johnson , Jeffrey Electrical Engineering and University of Toledo, Toledo, OH	PhD 99-0823	WL/FI	01/01/99	12/31/99	$25000.00	$10075.00
		Incorporating Fixed, Adaptive, & Learning Controllers to the Flight Control				
Kapila , Vikram Aerospace engineering Polytechnic Inst of New York, Brooklyn, NY	PhD 99-0820	WL/FI	01/01/99	12/31/99	$25000.00	$17448.00
		Dynamics and Control of Spacecraft Formation Flying				
Kihm , Kenneth Mechanical Engineering Texas Engineering Experiment Station, College	PhD 99-0821	WL/FI	01/01/99	12/31/99	$25000.00	$10310.00
		Micro-Scale Flow Field Measurement of the Thin Meniscus of Capillary-Driven Heat				
Li , Rongxing Photogrammertry & Remote Sensing Ohio State University, Columbus, OH	PhD 99-0831	WL/AA	01/01/98	12/31/98	$25000.00	$13183.00
		Uncertainty Modeling of Target Locations From Multiplatform and Multisensor Data				
Lin , Chun-Shin Electrical Engineering Univ of Missouri - Columbia, Columbia, MO	PhD 99-0826	WL/MN	01/01/99	12/31/99	$25000.00	$1991.00
		Sensor Fusion w/Passive Millimeter Wave & Laser Radar for Target Detection				
Liu , Chaoqun Applied Mathematics Louisiana Tech University, Ruston, LA	PhD 99-0819	WL/FI	01/01/99	12/31/99	$25000.00	$12521.00
		Boundary Conditions in Curvilinear Coordinates for Direct Numerical Simulation				

SREP SUB-CONTRACT DATA

Report Author Author's University	Author's Degree	Sponsoring Lab	Performance Period		Contract Amount	Univ. Cost Share
Mungan , Carl Dept of Physics University of Florida, Pensacola, FL	PhD 99-0824	WL/MN	01/01/99	12/31/99	$24914.00	$3276.00
		infrared Spectropolarimetric Directonal Reflectance and Emissivity of Mental Sur				
Ogale , Amod Chemical Engineering Clemson University, Clemson, SC	PhD 99-0817	WL/ML	01/01/99	12/31/99	$25000.00	$9000.00
		Structural Changes in Mesophase Pitch-Based Carbon Fibers:In SITU &ES SITU Measu				
Pidaparti , Ramana Aeronautics & Astronautics Indiana U-Purdue at Indianap, Indianapolis, IN	PhD 99-0822	WL/FI	01/01/99	12/31/99	$25000.00	$10582.00
		Benchmarking Aerodynamic Panel Methods for Flight Loads in Multidisciplinary Opt				
Saddow , Stephen Electrical Engineering Mississippi State University, Mississippi State,	PhD 99-0827	WL/PO	01/01/98	12/31/98	$25000.00	$0.00
		Silicon Carbide Implant Activation & Surface preparation Investigation				
Sepri , Paavo Engineering Science Florida Inst of Technology, Melbourne, FL	PhD 99-0836	WL/PO	01/01/99	12/31/99	$25000.00	$6519.00
		Computational Study of Unsteady Flow Interactions Between Turbine Blades, Cylind				
Shi , Hongchi Computer Engineering Univ of Missouri - Columbia, Columbia, MO	 99-0825	WL/MN	01/01/99	12/31/99	$25000.00	$15851.00
		Developing an efficient Algorithm for Routing Processors of the VGI Parallel Com				
Soumekh , Mehrdad Elec/Computer Engineering SUNY Buffalo, Amherst, NY	PhD 99-0807	WL/AA	01/01/99	12/30/99	$25000.00	$0.00
		Signal and Image Processing for FOPEN/GPEN SAR				
Riviello , Craig Mechanical Wright State University, Dayton, OH	BS 99-0837	WL/ML	01/01/99	01/01/99	$25000.00	$6304.00
		In-Situ Synthesis of Discontinuously Reinforced Titanium alloy Composites Via Bl				

APPENDIX 1:

SAMPLE SREP SUBCONTRACT

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
1999 SUMMER RESEARCH EXTENSION PROGRAM
SUBCONTRACT 99-0806

BETWEEN

Research & Development Laboratories
5800 Uplander Way
Culver City,CA 90230-6608

AND

Penn State Erie, The Behrend College
Contracts and Grants Office
Erie, PA 16563

REFERENCE:	Summer Research Extension Program Proposal			98-0029
	Start Date: 01/01/99		End Date:	12/31/99
	Proposal Amount:	$25,000		
	Proposal Title:	Image Quality Assessment for ATR Applications Using Multiresolutional Informational Information Metrics		

PRINCIPAL INVESTIGATOR: Dr. Farid Ahmed
Penn State Erie, The Behrend College
Erie, PA 16563

(2) UNITED STATES AFOSR CONTRACT NUMBER: F49620-93-C-0063

(3) CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER (CFDA):12.800
PROJECT TITLE: AIR FORCE DEFENSE RESEARCH SOURCES PROGRAM

(4) ATTACHMENTS
1. REPORT OF INVENTIONS AND SUBCONTRACT
2. CONTRACT CLAUSES
3. FINAL REPORT INSTRUCTIONS

*****SIGN SREP SUBCONTRACT AND RETURN TO RDL*****

1. BACKGROUND: Research & Development Laboratories (RDL) is under contract (F49620-93-C-0063) to the United States Air Force to administer the Summer Research Program (SRP), sponsored by the Air Force Office of Scientific Research (AFOSR), Bolling Air Force Base, D.C. Under the SRP, a selected number of college faculty members and graduate students spend part of the summer conducting research in Air Force laboratories. After completion of the summer tour participants may submit, through their home institutions, proposals for follow-on research. The follow-on research is known as the Summer Research Extension Program (SREP). Approximately 61 SREP proposals annually will be selected by the Air Force for funding of up to $25,000; shared funding by the academic institution is encouraged. SREP efforts selected for funding are administered by RDL through subcontracts with the institutions. This subcontract represents an agreement between RDL and the institution herein designated in Section 5 below.

2. RDL PAYMENTS: RDL will provide the following payments to SREP institutions:

- 80 percent of the negotiated SREP dollar amount at the start of the SREP research period.
- The remainder of the funds within 30 days after receipt at RDL of the acceptable written final report for the SREP research.

3. INSTITUTION'S RESPONSIBILITIES: As a subcontractor to RDL, the institution designated on the title page will:

a. Assure that the research performed and the resources utilized adhere to those defined in the SREP proposal.

b. Provide the level and amounts of institutional support specified in the SREP proposal..

c. Notify RDL as soon as possible, but not later than 30 days, of any changes in 3a or 3b above, or any change to the assignment or amount of participation of the Principal Investigator designated on the title page.

d. Assure that the research is completed and the final report is delivered to RDL not later than twelve months from the effective date of this subcontract, but no later than December 31, 1998. The effective date of the subcontract is one week after the date that the institution's contracting representative signs this subcontract, but no later than January 15, 1998.

e. Assure that the final report is submitted in accordance with Attachment 3.

f. Agree that any release of information relating to this subcontract (news releases, articles, manuscripts, brochures, advertisements, still and motion pictures, speeches, trade associations meetings, symposia, etc.) will include a statement that the project or effort depicted was or is sponsored by: Air Force Office of Scientific Research, Bolling AFB, D.C.

g. Notify RDL of inventions or patents claimed as the result of this research as specified in Attachment 1.

h. RDL is required by the prime contract to flow down patent rights and technical data requirements to this subcontract. Attachment 2 to this subcontract

contains a list of contract clauses incorporated by reference in the prime contract.

4. All notices to RDL shall be addressed to:

RDL AFOSR Program Office
5800 Uplander Way
Culver City, CA 90230-6609

5. By their signatures below, the parties agree to provisions of this subcontract.

Abe Sopher RDL Contracts Manager	Signature of Institution Contracting Official
	Typed/Printed Name
Date	Title
	Institution
	Date/Phone

ATTACHMENT 2
CONTRACT CLAUSES

This contract incorporates by reference the following clauses of the Federal Acquisition Regulations (FAR), with the same force and effect as if they were given in full text. Upon request, the Contracting Officer or RDL will make their full text available (FAR 52.252-2).

FAR CLAUSES	TITLE AND DATE
52.202-1	DEFINITIONS
52.203-3	GRATUITIES
52.203-5	COVENANT AGAINST CONTINGENT FEES
52.203-6	RESTRICTIONS ON SUBCONTRACTOR SALES TO THE GOVERNMENT
52.203-7	ANTI-KICKBACK PROCEDURES
52.203-8	CANCELLATION, RECISSION, AND RECOVERY OF FUNDS FOR ILLEGAL OR IMPROPER ACTIVITY
52.203-10	PRICE OR FEE ADJUSTMENT FOR ILLEGAL OR IMPROPER ACTIVITY
52.203-12	LIMITATION ON PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS
52.204-2	SECURITY REQUIREMENTS
52.209-6	PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED, SUSPENDED, OR PROPOSED FOR DEBARMENT
52.212-8	DEFENSE PRIORITY AND ALLOCATION REQUIREMENTS
52.215-2	AUDIT AND RECORDS - NEGOTIATION
52.215-10	PRICE REDUCTION FOR DEFECTIVE COST OR PRICING DATA

52.215-12	SUBCONTRACTOR COST OR PRICING DATA
52.215-14	INTEGRITY OF UNIT PRICES
52.215-8	ORDER OF PRECEDENCE
52.215.18	REVERSION OR ADJUSTMENT OF PLANS FOR POSTRETIREMENT BENEFITS OTHER THAN PENSIONS
52.222-3	CONVICT LABOR
52.222-26	EQUAL OPPORTUNITY
52.222-35	AFFIRMATIVE ACTION FOR SPECIAL DISABLED AND VIETNAM ERA VETERANS
52.222-36	AFFIRMATIVE ACTION FOR HANDICAPPED WORKERS
52.222-37	EMPLOYMENT REPORTS ON SPECIAL DISABLED VETERAN AND VETERANS OF THE VIETNAM ERA
52.223-2	CLEAN AIR AND WATER
52.223-6	DRUG-FREE WORKPLACE
52.224-1	PRIVACY ACT NOTIFICATION
52.224-2	PRIVACY ACT
52.225-13	RESTRICTIONS ON CONTRACTING WITH SANCTIONED PERSONS
52.227-1	ALT. I - AUTHORIZATION AND CONSENT
52.227-2	NOTICE AND ASSISTANCE REGARDING PATIENT AND COPYRIGHT INFRINGEMENT

52.227-10	FILING OF PATENT APPLICATIONS - CLASSIFIED SUBJECT MATTER
52.227-11	PATENT RIGHTS - RETENTION BY THE CONTRACTOR (SHORT FORM)
52.228-7	INSURANCE - LIABILITY TO THIRD PERSONS
52.230-5	COST ACCOUNTING STANDARDS - EDUCATIONAL INSTRUCTIONS
52.232-23	ALT. I - ASSIGNMENT OF CLAIMS
52.233-1	DISPUTES
52.233-3	ALT. I - PROTEST AFTER AWARD
52.237-3	CONTINUITY OF SERVICES
52.246-25	LIMITATION OF LIABILITY - SERVICES
52.247-63	PREFERENCE FOR U.S. - FLAG AIR CARRIERS
52.249-5	TERMINATION FOR CONVENIENCE OF THE GOVERNMENT (EDUCATIONAL AND OTHER NONPROFIT INSTITUTIONS)
52.249-14	EXCUSABLE DELAYS
52.251-1	GOVERNMENT SUPPLY SOURCES

DOD FAR CLAUSES	DESCRIPTION
252.203-7001	SPECIAL PROHIBITION ON EMPLOYMENT
252.215-7000	PRICING ADJUSTMENTS
252.233-7004	DRUG FREE WORKPLACE (APPLIES TO SUBCONTRACTS WHERE THERE IS ACCESS TO CLASSIFIED INFORMATION)
252.225-7001	BUY AMERICAN ACT AND BALANCE OF PAYMENTS PROGRAM
252.225-7002	QUALIFYING COUNTRY SOURCES AS SUBCONTRACTS
252.227-7013	RIGHTS IN TECHNICAL DATA - NONCOMMERCIAL ITEMS
252.227-7030	TECHNICAL DATA - WITHOLDING PAYMENT
252.227-7037	VALIDATION OF RESTRICTIVE MARKINGS ON TECHNICAL DATA
252.231-7000	SUPPLEMENTAL COST PRINCIPLES
252.232-7006	REDUCTIONS OR SUSPENSION OF CONTRACT PAYMENTS UPON FINDING OF FRAUD

APPENDIX 2:

SAMPLE TECHNICAL EVALUATION FORM

SUMMER RESEARCH EXTENSION PROGRAM
TECHNICAL EVALUATION

SREP NO: 99-0828
PRINCIPAL INVESTIGATOR: Dr.Brian Jeffs
Brigham Young University

Circle the rating level number, 1 (low) through 5 (high), you feel best evaluate each statement and return the completed form by fax or mail to:

RDL
Attn: SREP Tech Evals
5800 Uplander Way
Culver City, CA 90230-6608

---

1. This SREP report has a high level of technical merit	1 2 3 4 5
2. The SREP program is important to accomplishing the lab's mission	1 2 3 4 5
3. This SREP report accomplished what the associate's proposal promised	1 2 3 4 5
4. This SREP report addresses area(s) important to USAF	1 2 3 4 5
5. The USAF should continue to pursue the research in this SREP report	1 2 3 4 5
6. The USAF should maintain research relationships with this SREP associate	1 2 3 4 5
7. The money spent on this SREP effort was well worth it.	1 2 3 4 5
8. This SREP report is well organized and well written	1 2 3 4 5
9. I'll be eager to be a focal point for summer and SREP associates in the future	1 2 3 4 5
10. The one-year period for complete SREP research is about right.	1 2 3 4 5

---

11. If you could change any one thing about the SREP program, what would you change:

____

____

____

12. What do you definitely NOT change about the SREP program?

____

____

____

PLEASE USE THE BACK FOR ANY OTHER COMMENTS

Laboratory: AFRL/IFEC
Lab Focal Point: Mr. Stanley Wendt
PHONE: (315) 330-7244

CONFLICT RESOLUTION IN DISTRIBUTED MEETINGS: USING COLLABORATION TECHNOLOGY TO SUPPORT BATTLE STAFF

Kenneth A. Graetz, Ph.D.
Assistant Professor
Department of Psychology

University of Dayton
300 College Park
Dayton, Ohio 45469-1430

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Summer Faculty Research Program
Armstrong Laboratory

Sponsored by:
Air Force Office of Scientific Research
Bolling Air Force Base, DC

and

Armstrong Laboratory

March 2000

CONFLICT RESOLUTION IN DISTRIBUTED MEETINGS: USING COLLABORATION TECHNOLOGY TO SUPPORT BATTLE STAFF

Kenneth A. Graetz, Ph.D.
Assistant Professor
Department of Psychology
University of Dayton

Abstract

Findings from two studies on conflict resolution in distributed groups are reported. Groups communicating via face-to-face, teleconferencing, and videoconferencing channels are compared. In Experiment 1, a common integrative bargaining task was used. In Experiment 2, a more realistic simulation was used in an attempt to emulate the behavior of battle staff interacting during periods of crisis. Both studies found evidence that visual access leads to higher levels of contentious communication and may interfere with decision-making. Videoconferencing may not be a desirable feature in a groupware tool designed to support conflict resolution or crisis management.

Conflict Resolution in Distributed Meetings:

Using Collaboration Technology to Support Battle Staff

In The Death of Distance, Cairnicross (1997) predicts the emergence of the networked computer as the main platform for supporting global communication and collaboration. This movement toward distributed teams, computer-mediated communication (CMC), and "groupware" is well underway in many organizations and will undoubtedly have profound organizational and psychological consequences. A growing body of theory and research emphasizes the importance of selecting the right tool for the task. For some collaborative activities, certain forms of technological support may be inappropriate and may even introduce new and substantial process losses. For example, a number of studies have demonstrated that synchronous, text-based messaging (i.e., electronic "chat") may be a poor medium for sharing and integrating information in distributed expert groups (Strauss, 1996). Similarly, the expected benefits of electronic brainstorming tools for promoting synergy and enhancing creativity have largely failed to materialize in the laboratory. With the exception of rather large teams (N > 12; Gallupe, Bastianutti, & Cooper, 1991), computer-supported brainstorming groups tend to perform about as well as unsupported groups, who in turn tend to generate as many ideas as isolated individuals, if not fewer (Diehl & Strobe, 1987). Thus, the allure of inexpensive distributed collaboration should be balanced by a firm understanding of the connection between technological support and group task characteristics.

A potential task-technology mismatch involves the use of videoconferencing to support negotiation and bargaining processes. In organizational environments, the growing interest and investment in videoconferencing technology is being driven largely by a desire to "look the other person in the eye." Presumably, this is deemed important when engaging in distributed interactions wherein trustworthiness must be either assessed or communicated. Research suggests that individuals view videoconferencing as more enjoyable, more informative, and more personal than other forms of CMC (Tang & Isaacs, 1993). However, there is also evidence that negotiators use the visual channel to dominate, deceive, threaten, or pressure their opponents and rely heavily on visual cues (e.g., staring) to assess the degree to which an opposing negotiator is trying to dominate them. In a study by Carnevale, Pruitt, and Seilheimer (1981), for example, negotiators who felt accountable to a constituent and who had direct visual access to the opposing negotiator engaged in more contentious behavior and obtained significantly lower

outcomes than negotiators who could not see one another. This suggests that the strong preference for videoconferencing as a means of building trust between two distributed parties may be misguided. The current study attempts to replicate and extend the Carnevale, Pruitt, and Seilheimer findings by comparing negotiations in three different communication modalities: face-to-face (FTF), teleconferencing (TELE), and videoconferencing (VC). It was hypothesized that visual access, either FTF or VC, would lead to poor negotiation performance, relatively high levels of frustration and contentious behavior, and low levels of trust. Restricting visual access (i.e., TELE) would presumably reduce the level of contentious behavior and promote interest integration (i.e., logrolling) and the development of trust. A study testing these hypotheses was conducted by the primary investigator as part of the 1998 SFRP.

Experiment 1

Method

Participants

One hundred and thirty four undergraduates, 68 females and 66 males, participated in the study in partial fulfillment of an introductory psychology research requirement.

Independent Variables

Communication. Dyads were randomly assigned to one of three communication conditions: FTF, TELE, or VC. In the FTF condition, negotiators sat across a table from one another in a private room. Negotiators used notebook computers during the negotiation that did not obstruct negotiators' visual access. In the TELE condition, negotiators were seated in private cubicles (approximately 6 sq. ft), each equipped with a small table, a headset (i.e., hands free) telephone, and a PC. In the VC condition, participants were also seated in private cubicles. The VC connection allowed negotiators to see and hear one another. The VC system provided high quality video and audio over an ISDN line. Video was close to broadcast quality with no noticeable voice lag.

As illustrated in Figure 1, the video window was located in the upper corner of the 17 in color monitor. The cameras were positioned approximately 2.5 ft from the faces of the negotiators and pointed at a slight downward angle. This provided a good view of the opponent's face and upper torso. All discussions were audio taped.

Accountability. Dyads were randomly assigned to either the accountable or not accountable condition. Using a protocol similar to that used in other studies, experimenters told accountable

negotiators that their respective "supervisors" would monitor the session. Participants were told that the experimenters would be playing the supervisory roles. Experimenters instructed participants,

> "Although I will not communicate with you at any point during the negotiation, I will be able to hear the discussion. As your supervisor, I will be evaluating your performance as a negotiator using a standard Negotiation Effectiveness Checklist. Based on your performance during the negotiation, you will receive a certain proportion of the total points that result from the final agreement. If I evaluate your performance positively, you will get all of the points. If I evaluate you negatively, you will only get a portion of the points. Remember, as your supervisor I want you to negotiate the best agreement for our side that you can."

In the not accountable condition, the supervisor section of the introduction protocol was omitted. Participants in this condition were simply told to, "Try to negotiate the best agreement for yourself that you can."

Negotiation Task

All dyads engaged in a 4-issue integrative bargaining task similar to those used and described extensively elsewhere (see Pruitt & Lewis, 1975; Thompson & Hastie, 1990; Thompson, 1991). As listed in Table 1, payoff schedules displayed five discrete levels per issue, with points per level listed in parentheses. The task involved the purchase of land from a state land manager by a developer interested in building an amusement park. The negotiation included one compatible issue, the earliest date for opening the park (Opening Day), and one zero-sum issue, the percentage of the park's gross that would go to the state (Gross). Negotiators' point distributions on the compatible issue were identical. For the zero-sum issue, the two negotiators' point distributions, while equal in magnitude, reflected diametrically opposed preferences. The other two issues, the number of acres sold (Acres) and the percentage of instate park employees (Instate), combined to form a logrolling pair. Although interests on both issues were opposed, each logrolling issue was less important to one negotiator than to the other. The developer valued Acres over Instate, while the buyer preferred Instate to Acres.

As illustrated in Figure 1, all negotiators viewed a computerized version of their payoff schedule, which was located in the lower half of the computer screen. The issue levels and points

per level were displayed in menus that dropped down when clicked with the mouse. Negotiators could then click on an issue level and their total points would be calculated and displayed in a box. Thus, negotiators could use this tool to compute the number of points that they would earn for any potential agreement. At no point during the session were the contents of this window transmitted to the other negotiator. Negotiators were only privy to their own payoff schedules.

Procedure

Participants arrived in same-gender pairs. During the recruitment phase, an experimenter ensured that the dyads were unfamiliar with one another. Two experimenters conducted each session. Upon arrival, participants sat at private desks to minimize pre-experimental contact and discussion. After obtaining informed consent, participants read a page of introductory material that described their role, the negotiation issues, and the method of payment. Individuals earned $5 for their participation in the study plus a chance to win a $100 bonus prize. The instructions informed each individual that, following completion of the entire study, the names of individuals who earned a high number of points in the negotiation would be entered into the drawing for the $100. The instructions informed participants that the probability of a tie was quite high and that the recipient of the prize would, "...most likely be selected randomly from among the top point earners." All negotiators were told to, "try to reach a deal that results in the best possible outcome for yourself or for your company."

Experimenters then escorted participants in the FTF condition to the meeting room. Lines of communication were opened between negotiators in the TELE and VC conditions. An experimenter introduced the negotiators to one another by role and advised them as to the 30-min time limit and the consequences of not reaching an agreement. Dyads that failed to reach an agreement within 30 min received 0 points for the negotiation. Experimenters told dyads that a 2-min warning signal would be provided at the 28-min mark. Experimenters informed negotiators that they were not allowed to show their payoff schedules to their opponents during the session.

The experimenters timed the duration of the session. After reaching an agreement, participants in the FTF condition returned to their private rooms. Lines of communication were closed in the TELE and VC conditions. Participants then completed the post-negotiation questionnaire. Finally, experimenters paid and debriefed the participants.

Dependent Variables

Agreements. Analyses were conducted using time to decision and total points across all four issues as dependent variables. In addition, outcomes on the logrolling issues and the compatible issue were analyzed separately. A logrolling score was constructed where 2 = complete logrolling (each negotiator conceded all points on the lesser issue while gaining 4000 points on the more important issue), 1 = partial logrolling (each negotiator settled for 400 points on the lesser issue while earning 3000 points on the more important issue), 0 = distributive solution (negotiators agreed to split both issues down the middle), –1 = win/lose solution (one negotiator managed to exceed his or her distributive outcome on both issues simultaneously and at his or her opponent's expense), and –2 = lose/lose solution (negotiators reached an agreement that resulted in both obtaining less than the distributive total, essentially logrolling backwards). A score for the dyad was obtained by averaging across negotiators. Performance on the compatible issue was assessed using the total points obtained on that issue.

Post negotiation questionnaire. The post-negotiation questionnaire assessed perceived issue importance and conflict of interest, frustration, trust, and various contentious behaviors. [Note. Specific descriptions of these variables were omitted for the sake of brevity].

Results

Agreements

All of the dyads reached agreement within the time allotted. Averaged across all conditions, the duration of the negotiation was 9.07 min (SD = 4.47). A univariate analysis of variance (ANOVA) using time to decision as the dependent variable[1] obtained a significant main effect for communication condition, $F(2, 53) = 4.11$, $p < .05$. Average time to decision (SD in parentheses) was 11.10 min (4.09), 8.98 min (4.77), and 7.13 min (3.72) for the FTF, TELE, and VC conditions, respectively. Pairwise comparisons using a Tukey HSD test revealed a significant difference between the FTF and VC conditions, with negotiators interacting significantly longer in the FTF condition.

Averaging across all conditions, dyads earned 13,400 points[2] (SD = 1150), a value significantly greater than the distributive total (12,800), $t(64) = 4.20$, $p < .001$, but significantly less than the integrative total (15,200), $t(64) = -12.61$, $p < .001$. An ANOVA using total points as the dependent variable revealed a significant communication main effect, $F(2, 53) = 3.53$, $p < .05$. The average point total (SD in parentheses) was 13,800 (693), 13,487 (1431), and 12,905

(1035) in the FTF, TELE, and VC conditions, respectively. Pairwise comparisons using a Tukey HSD test obtained a significant difference between the FTF and VC conditions only, with negotiators earning significantly more points overall in the FTF condition. The ANOVA also obtained a significant main effect for gender, $F(1, 53) = 4.62$, $p < .05$. Female dyads earned significantly fewer points overall than male dyads (Ms = 13,006 and 13,697, respectively; SDs = 1191 and 1074, respectively).

Analyzing the logrolling issues separately, 12% of the dyads successfully logrolled, 20% partially logrolled, 17% reached a distributive solution, 45% achieved a win/lose solution, and the remaining 6% arrived at a lose/lose solution. An ANOVA using the logrolling score as a dependent variable obtained a significant main effect for communication, $F(1, 53) = 4.06$, $p < .05$. The average logrolling score (SD in parentheses) was –0.33 (1.06), 0.39 (1.34), and –0.48 (0.93) in the FTF, TELE, and VC conditions, respectively. Pairwise comparisons using a Tukey HSD test obtained a significant difference between the TELE condition and both the FTF and VC conditions. Table 2 lists the percentages of logrolling, distributive, win/lose, and lose/lose solutions by communication condition. Significantly more logrolling occurred in the TELE condition than in either the FTF or VC condition.

Trust

On the post-negotiation questionnaire, participants rated the degree to which they trusted the opposing negotiator (trust-other) and the perceived level of trust afforded them by their opponent (trust-you). The overall means for trust-other and trust-you were 6.79 ($SD = 1.30$) and 6.71 ($SD = 1.13$), respectively. An ANOVA using trust-you ratings as the dependent variable revealed no significant effects. An ANOVA using trust-other ratings as the dependent variable revealed a significant three-way interaction, $F(2, 53) = 3.39$, $p < .05$, illustrated in Figure 2. Simple comparisons using the pooled error term revealed no significant communication differences for accountable male dyads ($M = 6.59$, averaged across communication conditions). For accountable female dyads, trust-other varied by communication condition, with significantly greater levels of trust reported in the TELE condition versus the FTF condition, $t(10) = 3.05$, $p < .05$.

Conversely, in the not accountable condition, female negotiators' trust-other levels did not differ significantly across communication conditions ($M = 7.17$, averaged across communication conditions), however, male negotiators' trust-other levels were significantly greater in the TELE condition versus the VC condition, $t(8) = 2.61$, $p < .05$. The only significant gender difference

occurred in the not accountable/VC condition, $\underline{t}(8) = -2.44$, $\underline{p} < .05$, with female negotiators reporting significantly greater trust-other scores than male negotiators.

Contentious Behavior

On the post-negotiation questionnaire, participants rated the extent to which their opponent engaged in a variety of positive and negative behaviors. A series of ANOVAs using each behavior as a dependent variable revealed a number of significant effects. A significant main effect for communication condition emerged for the item "made concessions," $\underline{F}(2, 53) = 3.87$, $\underline{p} < .05$. Means for this item (SDs in parentheses) were 5.40 (1.30), 6.20 (0.75), and 5.31 (1.40) for FTF, TELE, and VC, respectively. Pairwise comparisons using a Tukey HSD test revealed that negotiators in the TELE condition perceived that their opponent made significantly more concessions than did negotiators in the VC condition.

The ANOVA also revealed significant three-way interactions for the items, "listened to my suggestions/interests," $\underline{F}(2, 53) = 4.42$, $\underline{p} < .05$, and "appeared genuinely friendly," $\underline{F}(2, 53) = 3.33$, $\underline{p} < .05$, with patterns similar to that obtained for trust-other. The means for these items are listed in Table 1.

Correlational Analyses

Table 4 lists the correlations between the post-negotiation items pertaining to opponents' behaviors and both perceived frustration and trust-other. Most of the items were significantly correlated with frustration such that, the greater perceived levels of negative behavior were associate with greater frustration and less trust. Further analyses examining the potential moderational effects revealed that communication condition significantly moderated the relationship between reported frustration and responses on the item, "appeared inflexible." $F(2, 59) = 4.55$, $p < .05$. Although significant correlations were observed between this item and frustration in both the VC, $r(20) = +.68$, $p < .01$, and FTF, $r(20) = +.61$, $p < .01$, conditions, the two were not correlated in the TELE condition, $r(22) = -.08$.

Discussion

Based on the Carnevale, Pruitt, and Seilheimer (1981) findings related to visual access and integrative bargaining, it was predicted that dyads in the TELE condition would have a more accurate impression of their opponent's interests, engage in less contentious behavior, and achieve better joint outcomes than dyads in the FTF and VC conditions. Although the communication channels investigated in the current study certainly differ along multiple

dimensions, the relative absence of major differences between FTF and VC negotiations is a strong indication that the two were qualitatively similar. Thus, it seems unlikely that the poor performance of VC negotiators was due solely to the quality of the visual channel.

Current results indicated that VC may not be the optimal medium for integrative bargaining. Negotiators in the VC condition spent less time negotiating, obtained lower outcomes overall, and engaged in less logrolling that dyads in the other communication conditions. As predicted, negotiators in the TELE condition performed relatively well in the absence of visual access. The study also suggested that the effects of communication condition on perceptions of trust are a complex function of negotiator gender and accountability. Future research should attempt to isolate the mechanisms that may be driving this interaction effect. Finally, the moderational effect of communication condition on the relationship between frustration and perceptions of inflexibility suggests that such perceptions may be strongly influenced derived by visual cues. Thus, one explanation for the superior performance of TELE negotiators may be that they were not exposed to visual indicators of inflexibility and positional commitment.

Experiment 2

The external validity of Experiment 1 is limited by the size of the group and the nature of the problem. Most organizational interactions involving the resolution of conflict occur in larger groups or teams (e.g.. 4 or more individuals). In addition, the most problematic and critical decisions are often made when the group is experiencing considerable external pressure (e.g., during times of crisis). Thus, the effectiveness of collaboration support in facilitating conflict resolution should be evaluated under these circumstances. The following study was conducted in fulfillment of the requirements of the 1999 SREP.

Method

Participants

Two hundred and forty undergraduate students, 120 males and 120 females, participated in the study in partial fulfillment of a course requirement in introductory psychology.

Procedure

Four participants, two males and two females, engaged in a fictitious group problem-solving task involving the crash of a military aircraft. The following scenario was described:

A fighter aircraft with two crew members that was carrying 4 wing-mounted bombs has crashed in a cornfield and slid into a farmhouse containing two occupants. This occurred in rural northwest Ohio at 11:00 p.m. on 24 January. It is now 11:10 and the outside temperature is 15 degrees Fahrenheit with a wind-chill of -5 degrees Fahrenheit. Local newspeople with cameramen will be arriving in the next hour. This is the latest crash in a recent nationwide series of military mishaps.

You are a member of the team that will determine what people and equipment are needed at the crash site in order to secure the site and begin an investigation. There are four members on this team including yourself and you will be coordinating the crash site supply and personnel needs with these individuals.

A transport aircraft will be landing at your location in 30 minutes. In order to have equipment loaded on the airplane a plan for loading the aircraft has to be prepared in the next 20 minutes. The aircraft will arrive at the closest airport to the crash site (10-minute drive to the site) in 2 hours. Follow-up support will be transported from your location by roadway and will arrive at the crash site in 6 hours.

Your task is to decide what people and equipment need to go via aircraft in order to arrive first at the crash site. You can take 15 people and 55 units of equipment. You can refer to the map of the crash site and the information below to make your decision. Aircraft debris is scattered over a 2400 square foot area. Local resources are limited, but you have transportation support and police support. The local police force will supplement your security police with 8 people.

Participants received a list of people and equipment (see Appendix A). All participants also had access to a map of the crash site (see Appendix B). Each participant

was asked to play a role in the scenario, with interests differing by role. Each role was assigned at random. The roles were described as follows:

Contracting Specialist

You are in charge of setting up contracts with local agencies for equipment or services that may be needed at the crash site. You can have three vehicles waiting when the aircraft lands to transport people and equipment to the crash site.

Supply Specialist

You are in charge of the Cold Weather Gear, Meals Ready to Eat, Flashlights, Perimeter Tape and Batteries and making sure that it all gets to the crash site on the transport aircraft.

Personnel Specialist

You are in charge on ensuring the maximum number of security police, public affairs personnel, maintenance personnel, medical personnel and lawyers arrive at the crash site quickly.

Transportation Specialist

You are in charge of ensuring that the transport aircraft is used to its potential. You are also in charge of making sure that the power equipment, light carts, cars and trucks arrive at the crash site quickly.

After studying the information and acquiring their roles, participants were given 20 (high time pressure) or 50 (low time pressure) minutes to reach a decision. They participated in either a FTF, TELE, or VC discussion. Ten groups were randomly assigned to each cell of the 2x3 experimental design. Participants in the TELE condition communicated via an open "conference call." Participants in the VC condition utilized White Pine's CU See Me Pro software. This allowed each person to see and hear all three members of the group. The cameras were arranged such that individuals could view the other members from the shoulders up. All discussions were tape recorded and coded for evidence of contentious communication. Each tape was coded by

two independent judges. Judges counted the frequency of statements that involved threats, explicit attempts to pressure or influence other group members to change their position, or positional commitments (i.e., refusals to change one's position on an issue). Interrater reliability for contentious statements was acceptable ($r = +.79$). The total number of contentious statements was computed by averaging across the two judges.

An attempt was also made to measure decision quality. An expert generated an "optimal" solution to the task (see Appendix B). As these were naïve subjects who were only asked to play the role of content specialists and lacked real expertise, a fairly liberal measure of decision quality was used. Each group's decision was reviewed by two judges familiar with the experiment, who compared it with the expert solution. Each judge rated the final decision on a 5-point scale from 1 (poor or very different from the expert decision) to 5 (excellent or very similar to the expert decision). Across all groups, an acceptable level of interrater reliability was obtained ($r = +.83$). Thus, the ratings of the two judges were averaged to obtain a single measure of decision quality for each group.

Results

Decision Quality

The average level of decision quality was 2.14 with a standard deviation of .75. There was considerable evidence that the undergraduates who comprised the groups had a very difficult time understanding and solving the problem. An ANOVA using decision quality as a dependent variable and time and communication channel as independent variables revealed a significant main effect for time, $F(1,54) = 13.31$, $p < .05$, and a significant time by channel interaction, $F(2,54) = 7.29$, $p < .05$. There was no significant main effect for communication channel and no significant interaction between communication channel and time.

Contentious Communication

In order to compare across time pressure conditions, the number of contentious statements in each group was divided by the number of minutes spent discussing the problem, yielding a "number of contentious statement per minute" measure. In general, discussions were fairly contentious, with an average of 0.54 ($SD = .07$) contentious statements per minute. An ANOVA revealed a significant main effect for time, $F(1, 54) = 20.52$, $p < .05$, with significantly greater levels of contentious communication in the 20 minute versus the 50 minute condition (Ms = .98 and .03, respectively). In addition, there was a significant main effect for communication

channel, $F(1, 54) = 9.84$, $p < .05$, with contentious statements significantly lower in the TELE condition versus both the FTF and VC conditions (Ms = .10, .77 and .65, respectively).

General Discussion

Although each study contains a number of flaws that limit their generalizability, they both illustrate the detrimental effects of visual access during communication that involves interest integration. In Experiment 1, superior solutions were achieved when visual access was restricted. Although there was no difference in decision quality in Experiment 2, there was significantly more contentious discussion in conditions allowing for visual access, both FTF and via a videoconferencing channel. A difference in decision quality was probably not obtained in Experiment 2 due to an apparent floor effect. The naïve undergraduate participants seemed to have great difficulty assuming the specific battle staff roles. Obviously, these individuals lacked the expertise and real world experience necessary to play these roles effectively. Future studies using this simulation should involve actual content experts and possibly actual battle staff personnel. This would allow for a more effective assessment of the behavioral impact of the various communication channels.

In conclusion, this research emphasizes the need to focus carefully on the characteristics of various groupware and CMC tools when developing a system to support conflict resolution and crisis management. The visual access provided by a videoconferencing tool may, at first glance, seem like an extremely important feature in a battle staff support system. This research suggests strongly however, that this feature might not only be unimportant, but might also be detrimental, complicating decision-making by increasing the likelihood of contentious communication.

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Footnotes

[1] All statistical tests used $\underline{\alpha} = .05$. For post hoc comparisons, $\underline{\alpha}_{FW} = .05$. All ANOVAs included communication, accountability, and gender as independent variables

[2] Reported point values were rounded to the nearest whole number.

Table 1

Park Developer and Land Manager Payoff Schedules for the 4-Issue Task

Park Developer's Payoff Schedule

Acres	Earliest Opening Day	% of Gross	% Instate Employees
110 Acres (4000)	1 Year (2400)	2% (2400)	10% (1600)
100 Acres (3000)	2 Years (1800)	4% (1800)	20% (1200)
90 Acres (2000)	3 Years (1200)	6% (1200)	30% (800)
80 Acres (1000)	4 Years (600)	8% (600)	40% (400)
70 Acres (0)	5 Years (0)	10% (0)	50% (0)

Land Manager's Payoff Schedule

Acres	Earliest Opening Day	% of Gross	% Instate Employees
110 Acres (0)	1 Year (2400)	2% (0)	10% (0)
100 Acres (400)	2 Years (1800)	4% (600)	20% (1000)
90 Acres (800)	3 Years (1200)	6% (1200)	30% (2000)
80 Acres (1000)	4 Years (600)	8% (1800)	40% (3000)
70 Acres (1600)	5 Years (0)	10% (2400)	50% (4000)

Note. Points for each issue are listed in parentheses. All payoff schedules used in the study presented levels for both players arranged from most to least preferred.

Table 2

Logrolling Performance by Communication Condition

Outcomes	FTF	Telephone	Videoconference
Complete Logrolling	9%	26%	0%
Partial Logrolling	14%	26%	19%
Distributive Solution	9%	17%	24%
Win/Lose Solution	68%	22%	48%
Lose/Lose Solution	0%	9%	9%

Table 3

Mean Responses to Contentious Behavior Items by Communication, Accountability, and Gender

	Not Accountable		Accountable	
	Male	Female	Male	Female
FTF				
Trust-Other	6.25	7.50	6.60	6.42
Listened-Other	6.58	7.88	7.70	6.83
Friendly-Other	6.92	7.50	7.40	7.08
Friendly-Own	7.33	7.25	7.60	7.33
Telephone				
Trust-Other	7.58	6.70	6.67	7.67
Listened-Other	8.08	7.30	7.75	8.08
Friendly-Other	7.83	6.80	7.08	8.42
Friendly-Own	7.75	7.30	6.75	8.42
Videoconference				
Trust-Other	5.75	7.33	6.50	6.33
Listened-Other	6.97	7.27	8.20	7.67
Friendly-Other	6.38	7.75	8.00	7.67
Friendly-Own	5.83	7.92	7.60	7.25

Table 4

Simple Correlations of Behavioral Items With

Frustration and Trust-Other

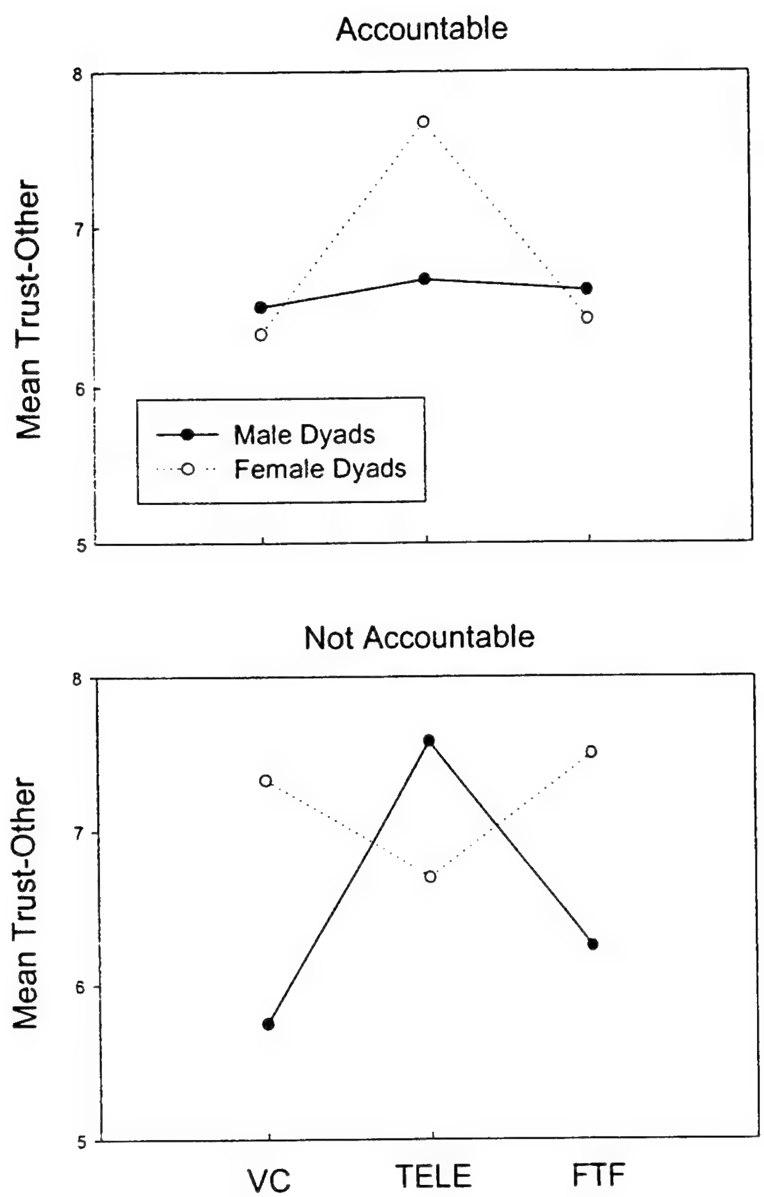
Items	r(frus)	r(trust)
Made concessions	-.32*	+.29*
Communicated interests	-.14	+.41*
Offered Alternatives	-.43*	+.40*
Interested in reaching agreement	-.50*	+.60*
Listened to my suggestions	-.26*	+.50*
Appeared friendly	-.35*	+.66*
Purposely misled	+.39*	-.50*
Used verbal pressure tactics	+.29*	-.28*
Used nonverbal pressure tactics	+.42*	-.50*
Appeared inflexible	+.40*	-.46*
Appeared mainly interested in self	+.23	-.27*

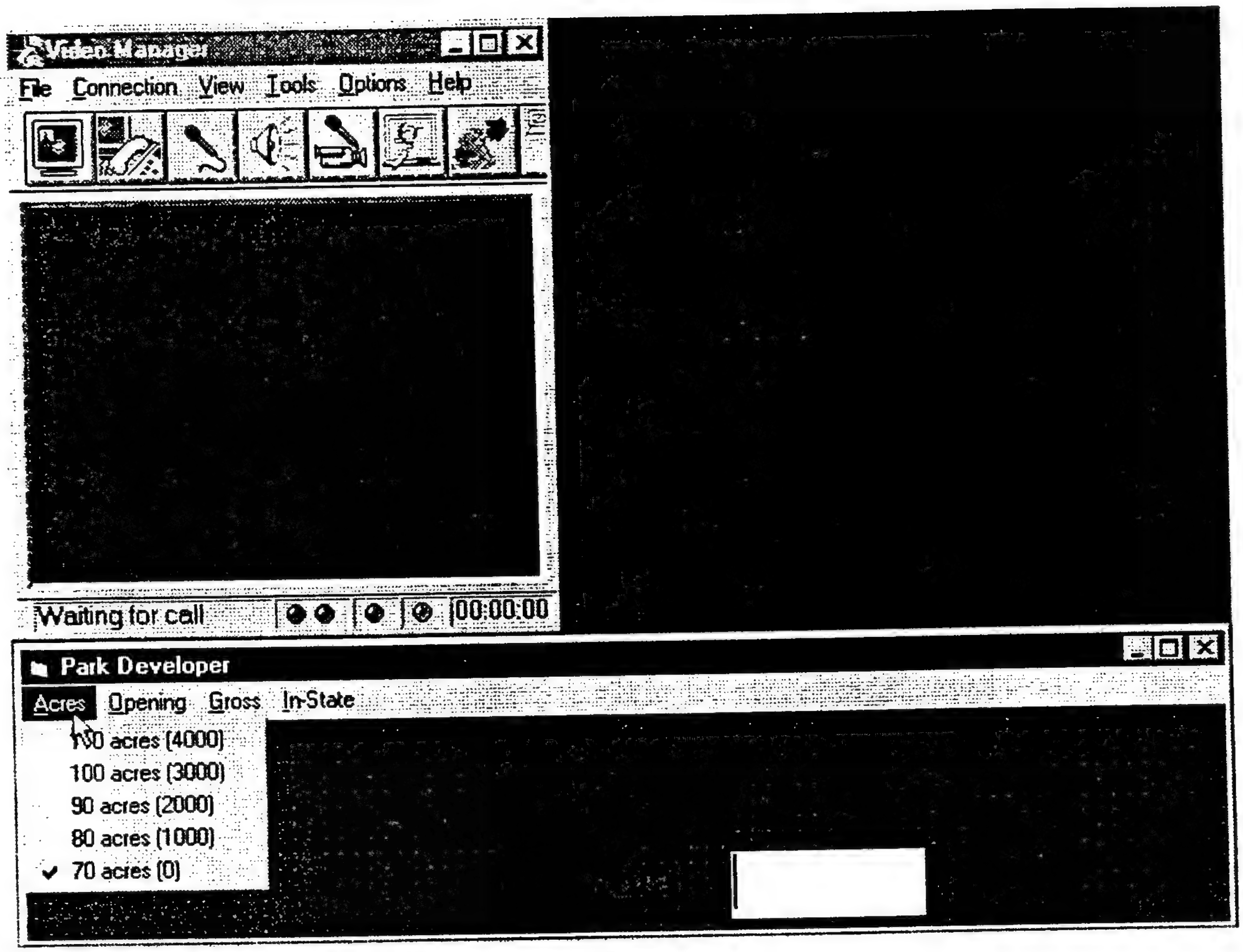
Figure Captions

Figure 1. Mean Responses on Trust-Other by Communication, Accountability and Gender

Figure 2. Screen Shot of Video Window and Computerized Payoff Schedule

Figure 3. Crash Site Map Used in Experiment 2


Accountable
Mean Trust-Other
8
7
6
5
Male Dyads
Female Dyads
Not Accountable
Mean Trust-Other
8
7
6
5
VC
TELE
FTF


Video Manager
File Connection View Tools Options Help
Waiting for call
00:00:00
Park Developer
Acres Opening Gross In-State
110 acres (4000)
100 acres (3000)
90 acres (2000)
80 acres (1000)
70 acres (0)

Appendix A

The List Of People and Equipment Used in Experiment 2

People available and their functions

10 Lawyers - Determine legality of federal jurisdiction over state and personal property. Estimate and obligate for compensatory damages.

100 aircraft maintainers - Identify aircraft components. Find flight recorders. Isolate hazardous aircraft parts and bombs. Locate and isolate bombs. A minimum of 5 maintainers are needed to disarm bombs.

10 public affairs people - Control media. Film and video crash recovery.

25 medical people - Support on-site personnel. Triage any civilian casualties. Recover and identify any aircrew bodies.

50 security policeman - Their job is to rope off the crash site. Protect military assets and personnel. Each security policeman can cover a roped area of 160'.

Equipment available and Units of Space Per Each Single Item

10 Light Carts	5
5 Cases of Flashlights (30 per case)	2
5 Cases of Cold Weather Gear (5 per box)	2
1 Case of Meals Ready to Eat (20 per box)	1
1 Crane Vehicle	10
25 Cases of 100 ft Perimeter Tape (25 per box)	1
2 Flatbed Trucks	10
15 Items of Power Equipment	5

10 Cars	5
5 4WD Trucks	7
2 Field Hospitals	9
3 Field Kitchens	5
100 Drums of Fuel (55 gal per drum)	2
250 Cases of Batteries (30 per case)	1
500 Containers of Water (10 gallons per container)	1

ALTITUDE DECOMPRESSION SICKNESS: MODELING AND PREDICTION

Nandini Kannan
Associate Professor
Division of Mathematics and Statistics

University of Texas at San Antonio
6900 N. Loop 1604 West
San Antonio, TX 78249

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ALTITUDE DECOMPRESSION SICKNESS: MODELING AND PREDICTION

Nandini Kannan
Associate Professor
Division of Mathematics and Statistics
University of Texas at San Antonio

Abstract

We investigate the use of survival models in predicting the probability of Altitude Decompression Sickness (DCS) as a function of several risk factors. A stratified loglogistic model was developed and fit to data from altitude chamber experiments conducted at Air Force Research Laboratory, Brooks Air Force Base. The model was used to predict the DCS incidence rates for a variety of exposures and the validity of the model evaluated. The effects of exercise at high altitudes were also investigated.

ALTITUDE DECOMPRESSION SICKNESS: MODELING AND PREDICTION

Nandini Kannan

1. INTRODUCTION

Decompression Sickness (DCS) occurs when individuals are exposed to significant changes in environmental pressure. Such changes may occur during exposure to high altitudes, or during ascent from depth. Examples of exposure to altitude include aircrews operating in unpressurized aircraft, passengers traveling in aircraft with inadequate pressurization, and astronauts performing extravehicular activity in space. DCS also occurs in divers who ascend very rapidly to the surface and among miners working in pressurized shafts.

The significant change in ambient pressure results in the inability of the gas exchange processes in the tissues to expel the excess nitrogen resulting in supersaturation. This causes nitrogen dissolved in the body to come out of solution. If nitrogen is forced to leave the solution very rapidly, bubbles form in different areas of the body causing a variety of symptoms. This phenomenon is based on the same principle that causes bubbles to form when a can of soda is opened.

The most common symptom associated with the formation of bubbles is pain in the joints and abdomen. causing the subject to "bend" over with pain. This is the reason behind the use of the word "bends" to describe DCS. The first documented case of DCS occurred in 1841 when coal miners complained of pain and muscle cramps. The mine shafts where these miners worked were air-pressurized to keep water out. This is why DCS is often referred to as Caissons Disease. Symptoms of DCS include joint pain, nausea, respiratory difficulties, central nervous system problems, and in severe cases paralysis and sometimes even death.

Altitude DCS became a common problem in the 1930's with the advent of high altitude balloon and aircraft flights. Increased technology has allowed the design of

aircraft that fly higher and faster. Most commercial aircraft are pressurized, and passengers very rarely experience any discomfort. However, many smaller aircraft are unpressurized and altitude DCS is a real risk when flying above 18,000 feet. Currently, U.S. Federal Aviation Regulations (FARs) require high-altitude physiology training for cockpit and cabin crews operating above 25,000 feet. The National Transportation Safety Board has also recommended additional physiology training for pilots flying in aircraft with ceilings at and above 18,000 feet.

The discovery that breathing 100% Oxygen before exposure to altitude (preoxygenation) significantly reduces the incidence of DCS was a major breakthrough. The preoxygenation washes out nitrogen from body tissues, delaying the onset of formation of bubbles and consequently symptoms. Military aircrews and astronauts routinely perform preoxygenation procedures followed by inflight oxygen breathing. However, the incidence of DCS also depends on the final altitude to which the individual is exposed, the length of the exposure, the level of physical activity performed during the exposure, and many other physical and physiological factors that affect bubble formation and growth. The risk of DCS may be eliminated/ decreased significantly by controlling the levels of these "risk factors"

The United States Air Force (USAF) and the National Aeronautics and Space Administration (NASA) conduct missions where their personnel are routinely exposed to high altitudes. The ability to predict DCS risk real-time, as well as for mission planning, is an operational need for both military and civilian aerospace applications. In order to predict the risk, we need to understand and assess the effects of the various risk factors, and incorporate that information in the development of an appropriate model.

To study the occurrence of altitude DCS and its' primary risk factors, the Air Force Research Laboratory at Brooks Air Force Base has for many years conducted research using human subjects exposed to simulated altitude in hypobaric chambers. The test subjects are exposed to different altitudes, varying denitrogenation times,

different breathing gas mixtures, and levels of exercise determined by the flight protocol. Subjects are monitored continuously for possible symptoms of DCS. The experiment either lasts the entire exposure period or is terminated when an individual exhibits symptoms. While at altitude, subjects are also monitored for venous gas emboli (VGE) using echocardiography. Data from these experiments has been deposited in the Air Force Research Laboratory database and provide the foundations for the modeling efforts.

Over the past several years, statistical and mathematical models have been developed to predict the probability/ risk of DCS for different flight profiles. The statistical models rely on survival analysis techniques to express the probability/ risk of DCS as a function of several risk factors. Earlier research showed that a model based on the log-logistic distribution provides excellent predictions for a variety of flight profiles. Over the last two years, a validation study was conducted at the Air Force Research Laboratory. The profiles for this validation study were carefully selected to fill gaps in the database, i.e. provide information on experimental conditions that are realistic but had not been part of previous studies. This data has allowed us to test the validity of the model and make necessary adjustments and modifications. The final validated model is the foundation of the development of a standardized Altitude Decompression Sickness Risk Assessment Computer (ADRAC) for DCS risk assessment and management in USAF flight and chamber operations. The ADRAC is currently under development and the final product should be available in the next few months.

During my tenure with the AFOSR Summer Research Extension Program, I have been actively involved in the model development and validation. In this report, I summarize the findings and results of this investigation.

2. BACKGROUND

The literature on DCS modeling is extensive, however a closer examination reveals the vast majority of papers and articles deal with diving models. In stark contrast,

there has not been a standardized approach for predicting DCS risk for altitude experiments. The few early articles that dealt with altitude DCS essentially modified the existing diving models to include altitude data.

This simplistic approach is flawed because of the fundamental differences that exist between altitude and diving exposures. There are certain characteristics that are unique to high altitude exposure and were ignored in these early articles. The first difference is the faster ascent rate in high altitude situations compared to the slower ascent rates for divers. In aircraft, there is a significant threat of instantaneous loss of pressure. Finally, and perhaps the most important difference is that while symptoms in diving exposures occur post mission, they occur during mission for altitude exposures. These differences illustrate the limited applicability of diving models in assessing and predicting DCS risk for altitude exposures.

In the recent years, a few articles have appeared that have proposed models for altitude DCS. However, a standardized approach does not seem to be available and very few models have been validated with actual experimental data. We provide a brief review of the relevant literature in this area.

One of the earliest attempts at modeling DCS was by Weathersby [1], [2]. Several probabilistic models were proposed for predicting the occurrence of DCS, and maximum likelihood methods were used to fit these models to DCS data. In the first article, the authors only considered the presence/ absence of symptoms as the response variable. In the second article however, they did incorporate some information on the time of onset of symptoms. The data used in both articles came from diving experiments. Van Liew, Conkin, and Burkard [3] developed a probabilistic model of altitude DCS based on mechanistic premises. The authors hypothesize that the the risk of DCS may be related to the number of bubbles that form in a unit of tissue, the volume of gas that can be liberated from a unit of tissue, and the time available for these processes to operate. A dose-response model was considered relating the probability of occurrence of symptoms and several independent

variables accounting for decompression stress. Mathematical equations describing the mechanistic premises of bubble growth were incorporated in the risk function. Several competing models were tested and evaluated on the basis of how well they fit the data which was an accumulation of records on human exposures from several different sources. The three independent variables used in the analysis were duration of 100% O_2 at ground level (preoxygenation), atmospheric pressure after ascent, and exposure duration. The major assumption that the authors made is that DCS incidence can be predicted from characteristics of bubbles. In their conclusions. the authors recognize that symptoms may be secondary to bubbles and suggest that their mechanistic premises be scrutinized and investigated further.

Another article which included mechanistic premises of bubble growth was by Gerth and Vann [4]. The authors developed an extensive model for determining DCS risk from statistical/ biophysical models of in vivo gas exchange and bubble growth and resolution. The equations considered in the paper describing bubble growth and resolution are similar to those in Van Liew et al. The models considered in the article are the standard dose-response models with the percentage of symptomatic individuals being the response variable. The unknown parameters in the model were estimated using maximum likelihood methods. In their conclusions and suggestions for future research, the authors state the need for onset times of symptoms to be included to provide a better assessment of DCS risk and for the model to be more realistic and utilize all available data from the experiment.

The approaches outlined in these articles have certain deficiencies. They rely heavily on the premise that DCS incidence can be predicted from characteristics of bubbles. Even though the link between bubble formation and DCS can be physiologically explained, it is entirely possible that symptoms may be secondary to bubbles. Most of these models involve complex equations describing bubble growth based on certain physiological assumptions. It is extremely difficult, in fact virtually impossible to verify these assumptions with real data. The only data on bubble characteristics is

limited to VGE measurements on the Spencer scale. These models only use the percentage of symptomatic individuals and ignore the symptom onset time. Information on asymptomatic individuals (a very large percentage of individuals complete the experiment without exhibiting any symptoms) is not adequately incorporated into the model. In addition, these models offer limited information about the effects and possible interactions of the different risk factors on the risk of DCS.

An examination of the database from chamber experiments reveals certain interesting characteristics of DCS and offers some insight into the best possible approach for modeling DCS.

- Not all individuals exposed to identical experimental conditions exhibit symptoms of DCS.
- The severity and breadth of symptoms for individuals who do experience DCS is extremely variable, ranging from dull knee pain to severe vision problems.
- The time of onset of symptoms varies significantly from individual to individual.
- An individual subject is sometimes required to perform identical exposures in successive weeks. The subject may or may not have the same reaction: i.e. there is very little certainty about an individual response.

These observations essentially reveal the stochastic nature of DCS-the onset of symptoms is not fixed but a random variable. This necessitates the use of Survival Analysis/ Reliability techniques to model the incidence of DCS.

The first attempts at utilizing Survival models for predicting DCS were in a series of papers by Kumar et al [5], [6], [7], [8]. Logistic and loglinear models were developed to predict DCS as a function of Tissue Ratio (a measure of tissue nitrogen decompression stress) and CMB (circulating microbubbles) status. Maximum likelihood techniques were used to estimate the parameters of the models, the response variable being the logarithm of symptom onset time. Conkin et al [9] in a recent article developed loglogistic survival models using data from 66 NASA and USAF hypobaric chamber tests. The models examined the effects of Tissue Ratio and exercise

status (yes, no) on the risk of DCS and also incorporated some of the mechanistic principles of bubble growth. These equations were similar to those in Van Liew and other related articles.

The articles in this second group were certainly a step in the right direction in terms of development of models for predicting DCS risk. The criticism that can be leveled against these articles is that they are limited to examining the effects of one or two risk factors on the probability of DCS. We know from experimental data that there are several competing factors that affect the risk of DCS. These factors may act individually or sometime interact with other factors. These risk factors include altitude, preoxygenation duration, exposure duration, breathing mixture. and level of exercise performed during the exposure. In order to develop a comprehensive model that describes altitude DCS, it is essential to include all these factors and determine their relative importance and account for their possible interactions. In addition, these models do not account for the varying number of subjects in different protocols and the large variation in exposure times.

To address these limitations, Kannan, Raychaudhuri, and Pilmanis [10] developed a model based on the loglogistic distribution incorporating several risk factors. The model was fit to data from the Air Force Research Laboratory database. The risk factors that were highly significant (p-value < 0.0001) were final pressure, ratio of preoxygenation to exposure time, and exercise level. The model also accounted for the large dispersion in exposure times by assigning weights to the observations. These weights were chosen inversely proportional to the variances of onset times. Maximum likelihood estimators of the unknown parameters were obtained using the LIFEREG procedure of the statistical package SAS. The estimated cumulative distribution function (cdf) was used to predict the probability of DCS for a variety of exposure profiles. Validation and cross validation techniques were used to evaluate the predictions from the model. The predictions from this model agreed closely with empirical data from the USAF database for a variety of different exposure profiles.

Kannan [11] conducted a further analysis of the loglogistic model. The author developed confidence bands for the survival and risk functions using bootstrap techniques. The 90 % confidence bands for most profiles contained the empirical distribution function, providing further evidence that the loglogistic model is indeed an excellent predictive model for most exposure profiles.

With additional data becoming available, it was evident that the model needed to be modified. At very high altitude, the effects of exercise are far more pronounced than at lower altitudes. To address the interaction of exercise and altitude, stratified models were developed in a report by Kannan [12]. This article also addresses the possibility of threshold at both the higher and lower altitudes for DCS. Webb et al [13] suggest that there is an abrupt increase in DCS symptoms with zero preoxygenation above 21,200 feet. In the report by Kannan, the author discovers a sharp incidence in DCS above 30,000 feet. To account for these thresholds, a stratified model was developed and the predictions improve dramatically over the previous loglogistic model.

In this report, we present the results obtained after adding the validation data to the database. The model was modified to account for this new data: in particular the data on heavy exercise helped to better evaluate and understand the effects on DCS symptoms. The data at 35,000 feet helped to separate the effects of rest, mild and heavy exercise and led to a better definition of the risk factors. We present the results of the final validated model.

In the next section, we discuss the role of survival analysis in DCS modeling and provide details about the loglogistic model.

3. METHODOLOGY

We have already alluded to the fact that the onset time of DCS symptoms is a random variable and is also affected by the various risk factors. From the database, we have also observed that not all individuals exposed to identical experimental conditions will have similar responses. Some individuals bend early into the exposure and

some do not bend at all. The same individual on two different days will have different response to the exposure. These observations lead us to the conclusion that survival analysis techniques are the most appropriate for developing models for predicting the probability/ risk of DCS.

Survival Analysis can briefly be described as a collection of statistical methods for analyzing data on the lifetime or failure time of humans or components. The primary variable of interest is the survival time, the time to occurrence of a given event. The event can be the time to development of a disease, response to a treatment, or death. For modeling altitude DCS, the survival time is the onset time of DCS symptoms. In the past, the literature on survival analysis focused on predicting the probability of survival or computing the average lifetime. However in recent years, the focus of research has been the identification of risk or prognostic factors related to the development of the disease or symptom. Appendix I provides some basic definitions from survival analysis. However, for a comprehensive treatment the reader is referred to the classic books by Lee [14], Lawless [15], and Kalbfleisch and Prentice [16].

To develop an appropriate model for predicting the risk of DCS, we must first decide on the most appropriate distribution for the DCS onset time T. There are several distributions that are commonly used in survival analysis, for example the exponential, gamma, Weibull, lognormal, and loglogistic. Each distribution has its unique functional form and characteristics and determines its corresponding survival and risk functions.

With several competing distributions, the choice of an appropriate model is crucial. This is where the risk function becomes an invaluable tool. The choice of the appropriate distribution is usually made by determining the shape of the risk function that best describes the data. The risk function can be a constant function of time (exponential), increasing/ decreasing (Gamma) or bathtub shaped, i.e. nonmonotonic (lognormal).

Since DCS symptoms are directly linked to the increasing levels of nitrogen in the

tissues, it is clear that the instantaneous risk of developing symptoms increases with increased exposure duration. However, because of denitrogenation, the risk starts to drop after it reaches a maximum. This information on the effect of increased exposure on symptom onset limits the choice of models to distributions whose risk function have an inverted bathtub shape. There are three well known distributions falling into this category :the lognormal, loglogistic, and inverse gaussian distribution.

Another unique characteristic of survival data is the notion of "censored" or incomplete data. When subjects are placed in the altitude chamber, they are constantly monitored for symptoms. The subject is brought down to ground level as soon as he or she experiences any symptoms associated with DCS. For these individuals. the time to onset of symptoms is available. However, several individuals do not exhibit any symptoms of DCS during the entire duration of the experiment. For these individuals, we have no information on their symptom onset time. It is possible that these individuals would become symptomatic if the exposure duration were increased. The observations are the "censored" observations and do provide valuable information. Any model that is developed for predicting the probability/ risk of DCS must use this information in an appropriate manner.

Once an appropriate model is selected, we may write the likelihood function which describes the probability of observing the actual data points and includes information from both censored and uncensored individuals. The survival function must be modified to include the risk factors through an appropriate function. The likelihood function depends on several unknown parameters corresponding to these risk factors as well as parameters unique to the underlying probability distribution. We maximize the likelihood function using SAS to obtain estimates of the underlying parameters.

In the paper by Kannan, Raychaudhuri, and Pilmanis [10], both the loglogistic and lognormal distributions were fit to the database. To examine the fit of the model, the loglikelihood values can be compared. Since both models produced almost identical loglikelihood values. the loglogistic model was selected because of its' simpler form.

The survival function for the loglogistic distribution is given by

$$S(t) = \frac{1}{1 + (\lambda * t)^{\gamma}}$$

where the parameter λ is related to the risk factors through the following function

$$\lambda = exp(-\beta' x)$$

Here x is the vector of risk factors, and β the vector of corresponding parameters. The parameter γ is the scale parameter for the loglogistic distribution. The hazard/risk function for the loglogistic distribution is given by

$$r(t) = \frac{\lambda\gamma(\lambda * t)^{\gamma-1}}{1 + (\lambda * t)^{\gamma}}.$$

The likelihood function is given by

$$L(\beta, \gamma) = \prod_{i=1}^{M} f(t_i) \prod_{j=1}^{N-M} S(t_j),$$

where $f(t)$ is the loglogistic probability density function, N is the total number of subjects, and M denotes the number of symptomatic individuals. The LIFEREG procedure of the statistical software package SAS can be used to maximize $L(\beta, \gamma)$ to obtain the maximum likelihood estimates of the parameters.

Once estimates of the unknown parameters β and γ are obtained, we may obtain estimates of the survival and risk functions, viz. $\hat{S}(t)$ and $\hat{r}(t)$ by replacing the parameters by their maximum likelihood estimates. These estimates can then be used to predict the probability/ risk of DCS over time for a variety of exposure profiles. The results obtained in the next section are modifications of the basic models outlined here.

There are two main problems that were investigated during this period:

- The effect of exercise at 35,000 feet and
- The modification of earlier models to include validation data.

4. RESULTS

For several years, the Air Force Research Laboratory has conducted data in altitude chambers on human subjects. The results of over 2000 experiments have been deposited into a database. Both male and female subjects participated in these studies. The subjects were all Air Force personnel aged 18-45 with similar physical characteristics, representative of the USAF rated aircrew population. The voluntary, fully-informed consent of the subjects used in this research was obtained in accordance with AFI 40-402.

The data collected in the study included the time to onset of DCS symptoms (ONSET), amount of time spent in preoxygenation (BR), pressure/ altitude (PRES), time at maximum altitude (TALT), and exercise code (EX). Subjects were monitored continuously for DCS and VGE. Other variables included in the database are gender, age of subject, blood pressure, measure of bodyfat, smoking status etc. The experiment either lasted the entire exposure period or was terminated if the individual had symptoms. For further details on the different profiles, refer to Webb et al [17].

For individuals reporting no symptoms, their onset time was replaced by their corresponding TALT times. A censoring variable (CENSOR) was created to indicate the status of each individual: 1–DCS and 0–No DCS (Censored).

The pressure levels used in the analysis ranged from 179 mm Hg to 493 mm Hg. The preoxygenation times ranged from 0 to 240 minutes. Different types of exercise were performed during altitude. These were classified as rest, mild exercise, or heavy exercise according to the oxygen consumption. All exposures in this database used the same ascent rate and the same breathing gas mixture. For some studies, the same individuals performed as many as 5 exposures. These studies were designed to test the effects of inflight denitrogenation or the effects of increasing exercise on DCS. To avoid any possibility of data contamination, we decided to use only results of the first exposures of these individuals. Even though this resulted in a smaller dataset, we felt that this would reduce the effects of susceptible or resistant individuals. We also deleted data from studies where the breathing mixture was different from 100 % O2

(3 % CO2 or 50-50 Mixture). With these deletions, the reduced dataset contained 1015 observations of which 522 (51 %) were censored. Several articles have appeared that deal in detail with specific studies from the database. The interested reader may refer to the articles by Sulaiman et al [18], Ryles et al [19], Webb et al [20], and [21].

The earlier model developed by Kannan et al [10] considered three risk factors: PRES, BRTALT (ratio of preoxygenation to exposure time), and EX. In most experiments, we found that individuals who prebreathed longer were more likely to be subject to higher altitudes or longer exposure periods. The BRTALT variable was created to remove this bias. Validation and cross validation techniques were used to conclude that predictions from this model agreed closely with empirical data for most exposure profiles. The model, however, did not perform satisfactorily for low preoxygenation times, and at high altitudes. The classification of exercise as rest, mild, and heavy did not seem adequate, especially at the higher altitudes. Because of the paucity of data on heavy exercise at that time, it seemed reasonable to consider only two cases : rest or exercise. At very high altitudes (30,000 +), the effects of even mild exercise were very pronounced. At 30,000 ft with mild exercise, almost 80 % of subjects bent, compared to 52 % at 29,500 ft. For the resting profile at 30,000 ft, 53 % of subjects reported symptoms. This suggested either a strong interaction effect between altitude and exercise or some sort of threshold at 30,000 feet. It has been observed in the literature that there is a lower threshold for altitude DCS, i.e. below 21,000 ft very few cases of DCS occur [13]. The risk increases sharply at altitudes above this threshold. It seems reasonable to assume such a threshold may exist at the higher altitudes.

Kannan [12] proposed a stratified model based on three strata The first strata consisted of pressure levels in the range (282 , 314], i.e. altitudes between 22.500 and 25,000 ft. The second strata consisted of pressure levels in the range (226, 282], i.e. altitudes between 25,000 and 30,000 ft. The final strata consisted of pressure levels in the range [179, 226], i.e altitudes above and including 30,000 ft. For each

strata, the exercise variable was defined appropriately and another risk factor measuring the interaction between pressure and exercise was added to the model. This model was a clear improvement over the earlier model for the high altitudes and low preoxygenation profiles.

We used this model to predict the DCS incidence for the validation profiles. There were certain problems that were apparent. The original dataset contained very few observations corresponding to Heavy exercise and low preoxygenation times. The validation data allowed us to make the necessary modifications.

We determined that stratification was still necessary. Strata 1 contains data upto and including 314 mm Hg, i.e. altitudes upto and including 22,500 feet. The second strata contains altitude data from 22,500 to 29,500 feet. The third strata contains data above 30,000 feet. The exercise variable was also modified in each strata and an interaction term between exercise and pressure added to the model. The reason for choosing these particular strata were the observation that the incidence of DCS increases sharply at 30,000 feet and decreases sharply at 22,500. We used the LIFEREG procedure in SAS to fit this model to the data. The results are provided in Tables 1-3. Note that for all three strata, the scale parameter is less than one indicating the risk function does indeed increase to a maximum and then decrease with increased exposure. The table provides the estimates of the parameters, the standard error of the estimates, and a chi-square value used to assess the relative importance of the different risk factors.

For Strata 1, the Preoxygenation variable is not significant. This is not surprising because most profiles in this range had zero preoxygenation times. The only profile that contained a non-zero preoxygenation time was the profile at 22,500 which had 15 minutes. Clearly altitude (pressure) is significant and so is the interaction between exercise and pressure. The intercept is large because at the lower altitudes, the baseline for DCS risk is fairly high (i.e. onset times are very large). This indicates that there is a substantial lag before symptoms occur. This is consistent with the

Table 1: Parameter estimates: Altitude $\leq$ 22,500 ft

Variable	DF	Estimate	Std. Err.	Chi-sq	p-value
INT	1	-64.385	13.226	23.69	0.0001
PRES	1	12.782	2.366	29.18	0.0001
BR	1	0.015	0.027	0.328	0.5666
EXPR	1	-0.232	0.086	7.32	0.0068
SCALE	1	0.81	0.09		

Table 2: Parameter estimates: 22,500 < Altitude $\leq$ 29,500 ft

Variable	DF	Estimate	Std. Err.	Chi-sq	p-value
INT	1	-7.350	6.734	1.191	0.2751
PRES	1	2.812	1.338	4.421	0.0355
BR	1	0.006	0.002	6.359	0.0117
EXPR	1	-0.223	0.064	12.043	0.0005
SCALE	1	0.537	0.04		

Table 3: Parameter estimates: 29,500 < Altitude

Variable	DF	Estimate	Std. Err.	Chi-sq	p-value
INT	1	-2.988	2.304	1.682	0.1947
PRES	1	1.737	0.420	17.071	0.0001
BR	1	0.004	0.001	20.363	0.0001
EXPR	1	-0.132	0.017	62.482	0.0001
SCALE	1	0.537	0.04		

belief that DCS is caused by increasing levels of nitrogen in the tissues. At the lower altitudes, the supersaturation of tissues takes longer.

For Strata 3. all the risk factors are highly significant. The most significant is the interaction between exercise and altitude. This is clearly true because even mild exercise at such high altitudes increases the formation of bubbles and results in very short onset times. This has also been observed in the abstract by Fischer et al [22].

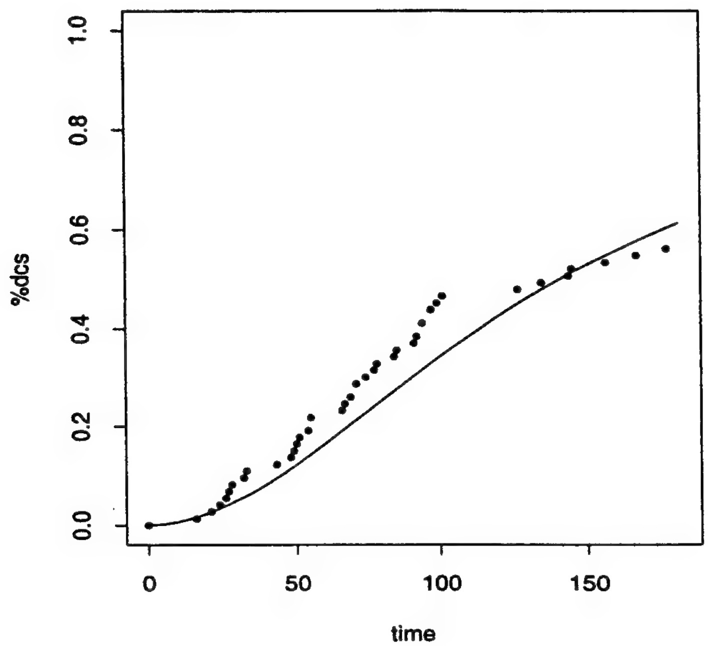
For Strata 2. this interaction term is again very significant. Preoxygenation time is significant but in the presence of altitude and exercise is of lower importance.

The results for all three strata indicate the relative importance of the three risk factors. However the interaction between exercise and altitude clearly has the most effect on increasing the risk of DCS. This is of significant operational importance in terms of mission planning. At very high altitudes, the results indicate exposure durations should be limited and exercise controlled. If these are not possible, the preoxygenation duration must be increased significantly.

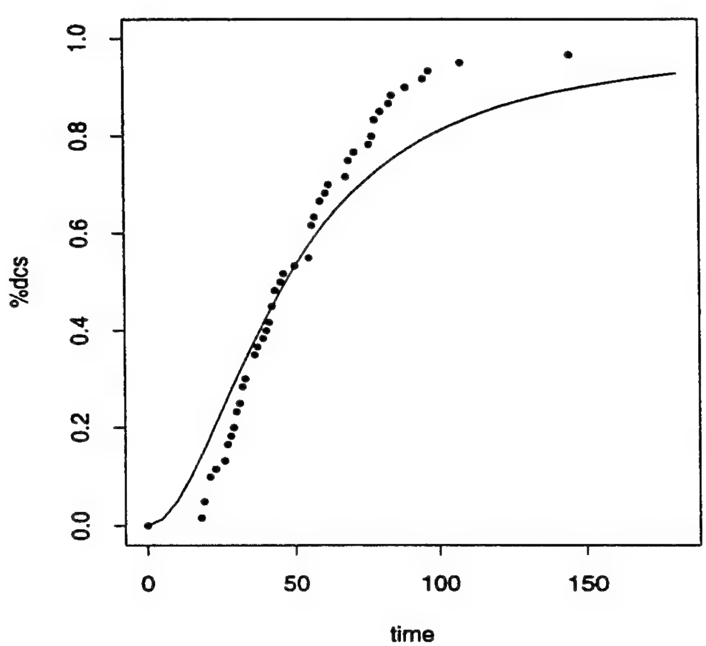
In order to evaluate the predictions from the model, we use the estimates obtained from SAS to predict the probability of DCS over time for several exposure profiles. The graphs are given below in Figures a-l. The solid line is the predicted probability of DCS over time using the stratified loglogistic model. The points represent the empirical probabilities from the database. We have selected profiles from all three strata to show the versatility of the model.

For most profiles the predicted and observed DCS incidences match. The fit is really very good for the higher altitudes. For the lower altitudes, there is some discrepancy due to the paucity of data.

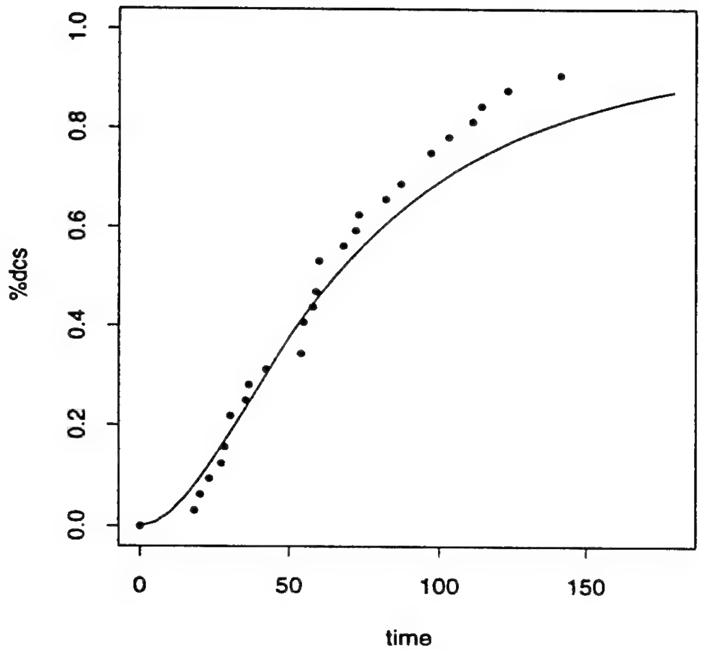
We next use the model to predict the probability of DCS as a function of preoxygenation time, exercise and altitude to see the effects of the factors holding the others constant. Figure 1 shows the effect of rest, mild and heavy exercise at 30,000 feet for a four hour exposure with 60 minutes of preoxygenation. The probability of symptoms increase as the exercise level increases. Figure 2 considers the effect of



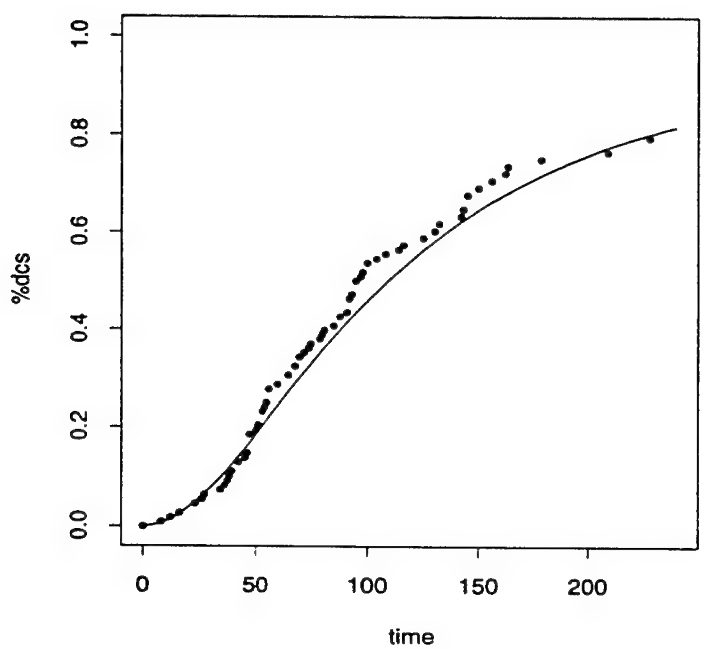
(a) PRES=179 mm Hg, BR=75 min, TALT= 180 min, Rest



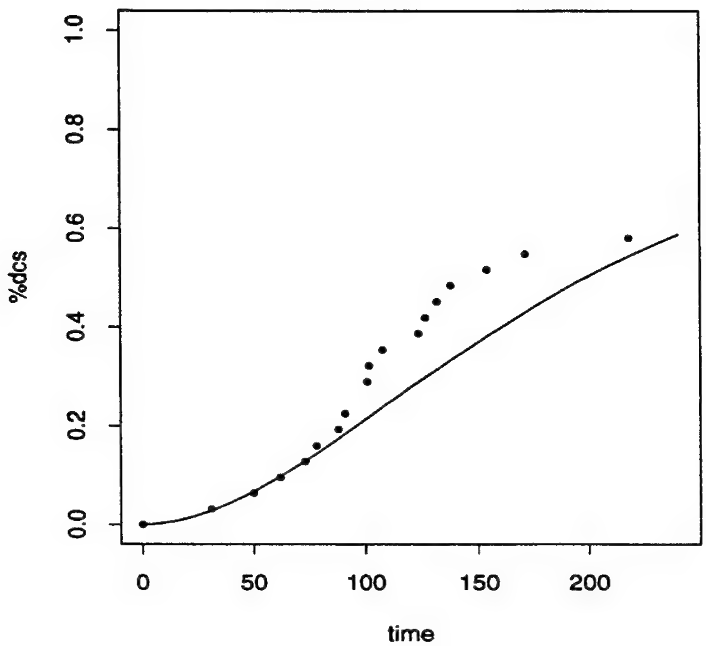
(b) PRES=179 mm Hg, BR=75 min, TALT= 180 min, Heavy



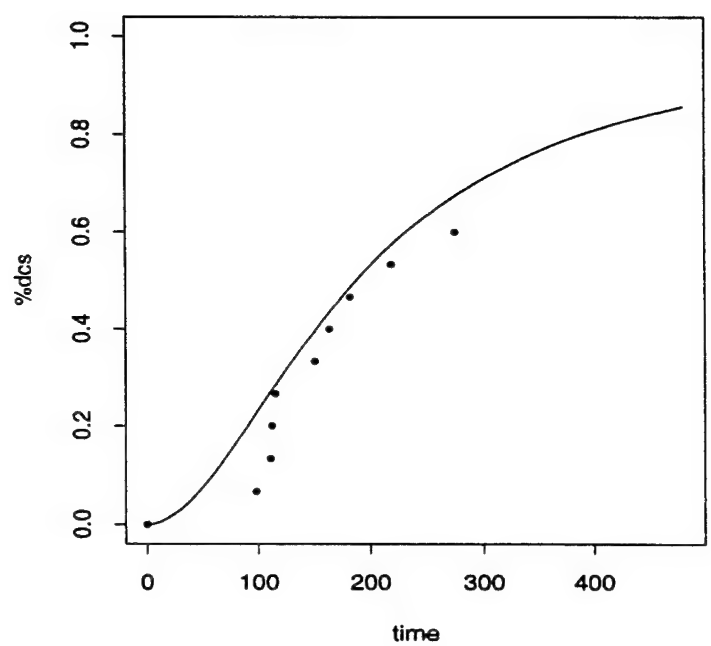
(c) PRES=179 mm Hg, BR=90 min, TALT= 180 min, Mild



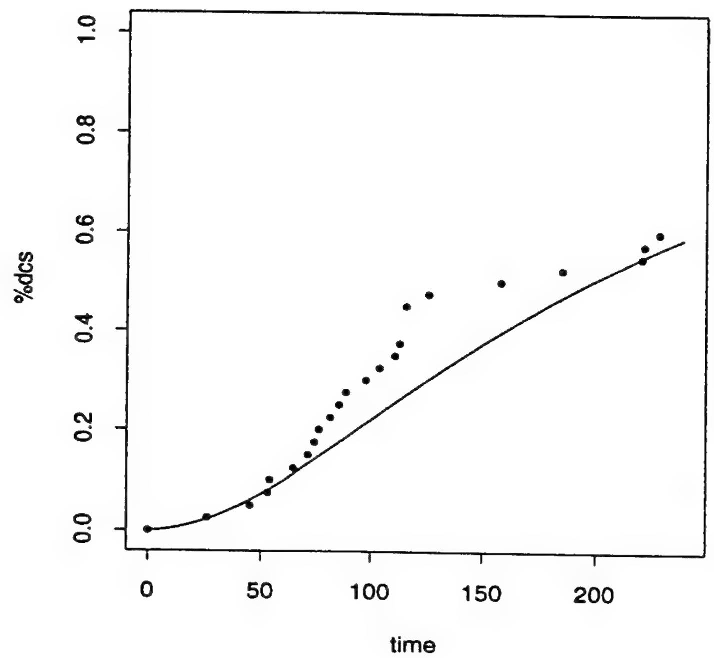
(d) PRES=226 mm Hg, BR=60 min, TALT= 240 min, Mild



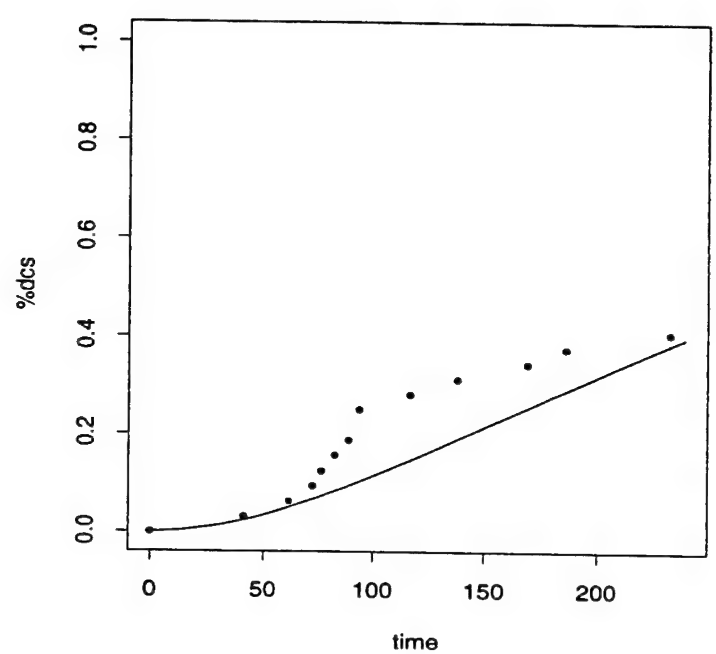
(e) PRES=226 mm Hg, BR=75 min, TALT= 240 min, Rest



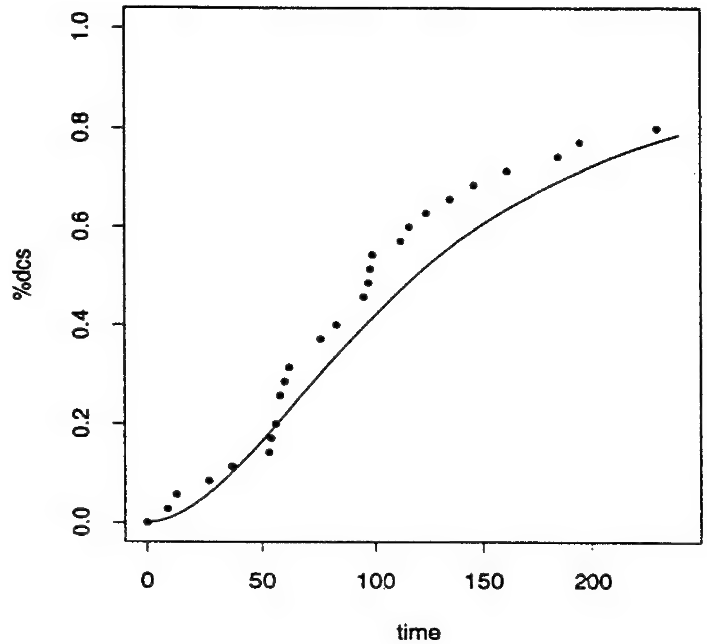
(f) PRES=226 mm Hg, BR=60 min, TALT= 480 min, Rest



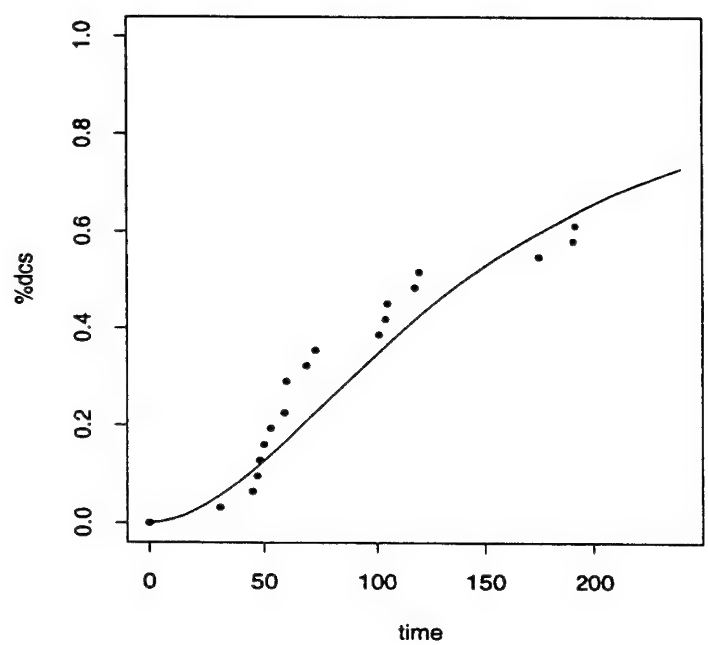
(g) PRES=231 mm Hg, BR=60 min, TALT= 240 min, Mild



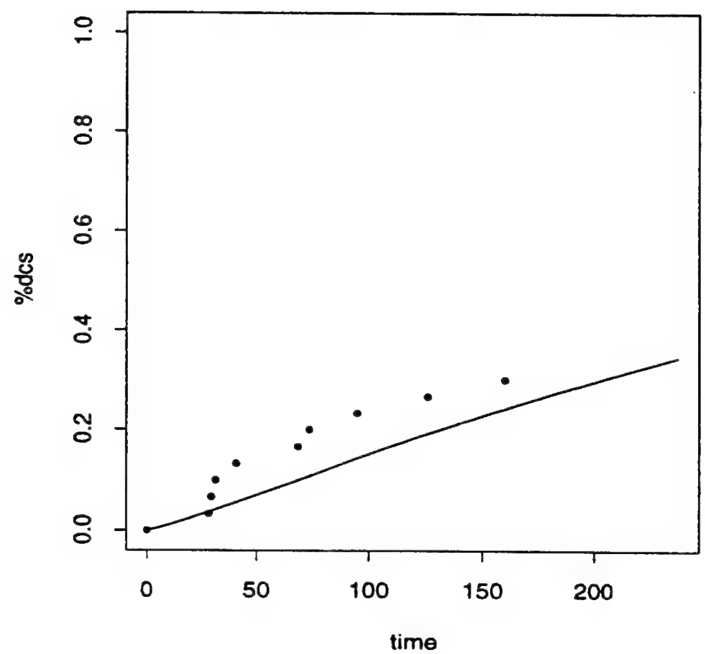
(h) PRES=231 mm Hg, BR=135 min, TALT= 240 min, Mild



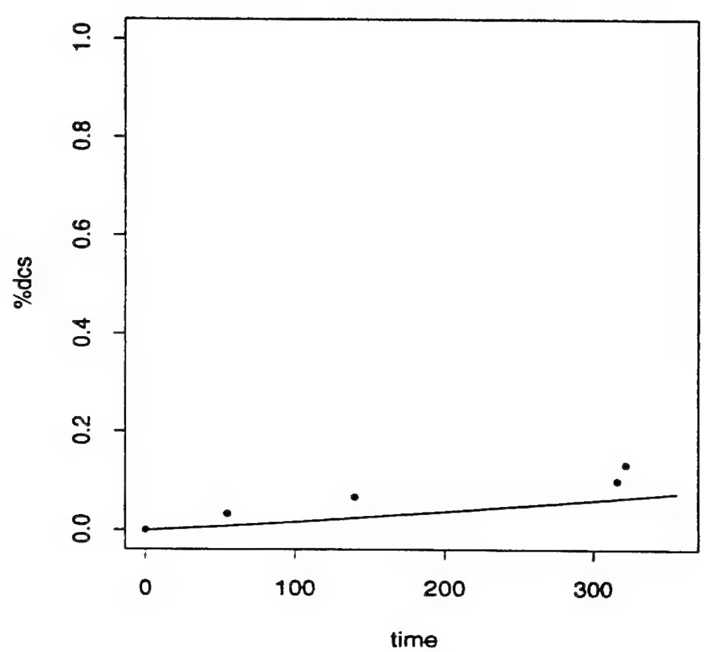
(i) PRES=282 mm Hg, BR=0 min, TALT= 240 min, Mild



(j) PRES=282 mm Hg, BR=30 min, TALT= 240 min, Heavy



(k) PRES=314 mm Hg. BR=15 min, TALT= 240 min. Heavy



(l) PRES=379 mm Hg, BR=0 min, TALT= 360 min. Heavy

increased preoxygenation times at 35,000 feet with Heavy exercise. Notice that at such extreme altitudes the difference between 60 and 90 minutes is not significant but a 4-hour preoxygenation does result in lower incidences. Figure 3 examines the effect of altitude for a 3 hour exposure with heavy exercise. To really delay the onset of symptoms, the altitude must drop to around 25,000 feet before a noticeable drop in the incidence is detected.

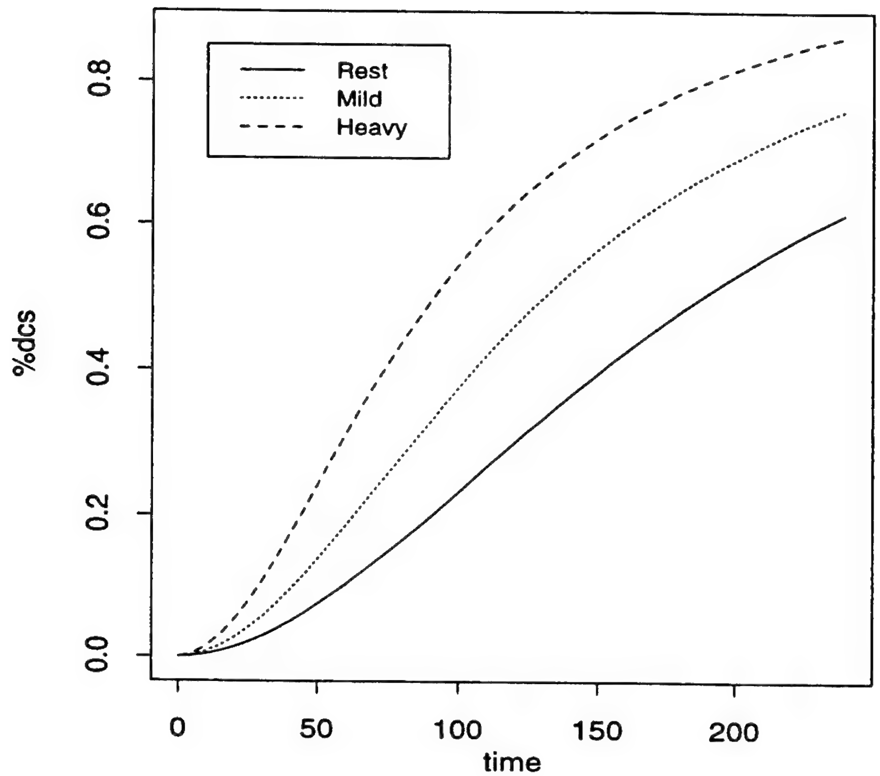


Figure 1: PRES=226 mm Hg, BR=60 min, TALT= 240 min

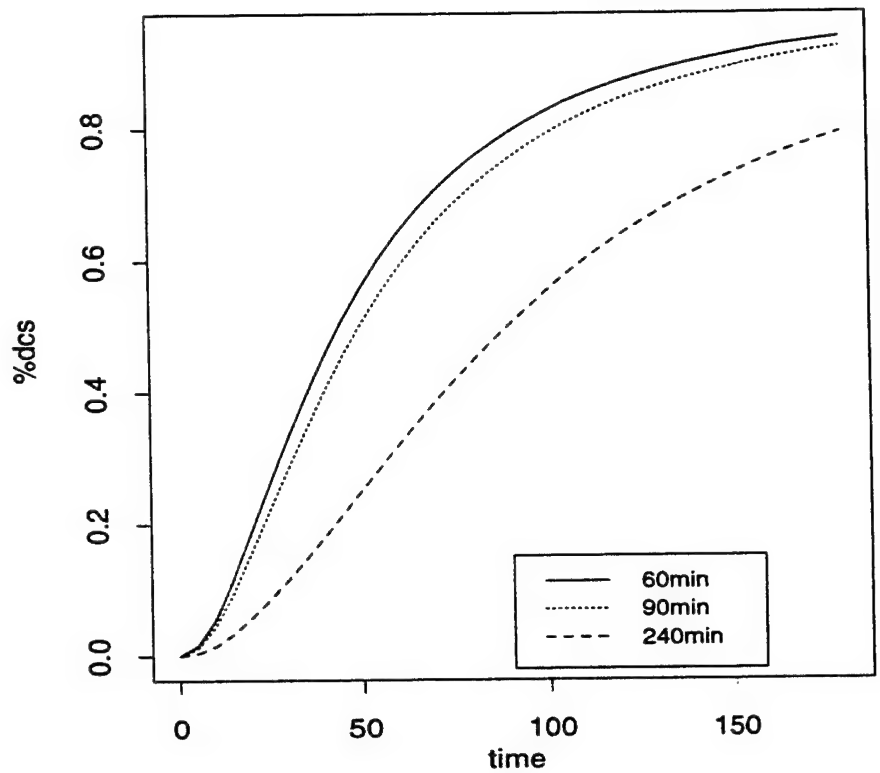


Figure 2: PRES=179 mm Hg, TALT= 180 min, Heavy

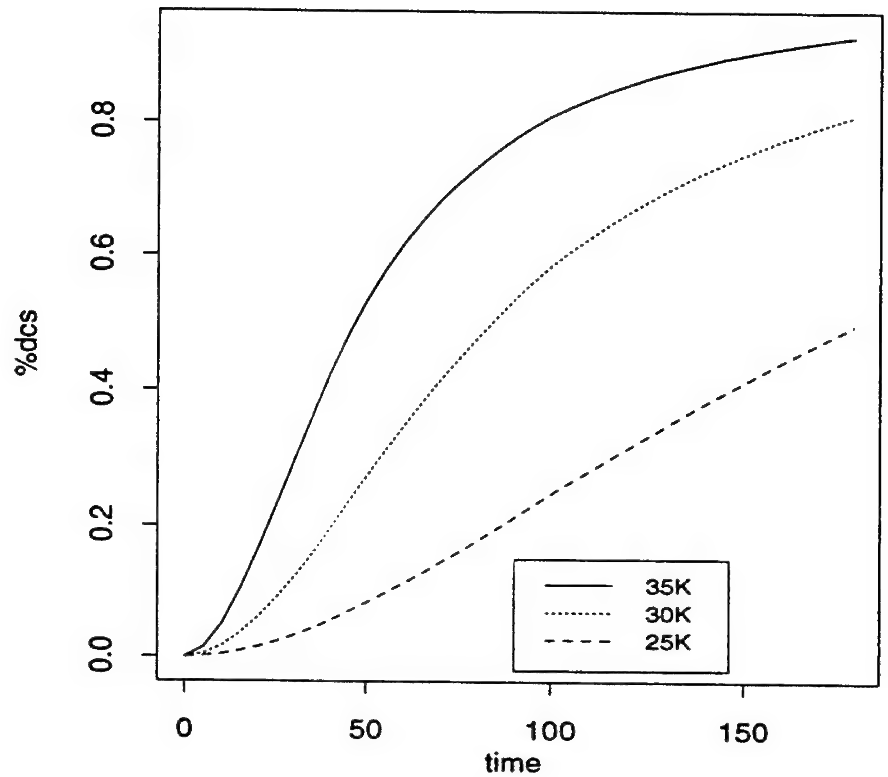


Figure 3: BR=75 min, TALT= 180 min, Heavy

4.1 Effects of Exposure to 35,000 feet

From the earlier results, it is clear that exposure to higher altitudes results in a significant increase in the DCS incidence and very short onset times. An extensive study was carried out and the results were consistent with the general findings stated above. Even mild exercise at 35,000 feet produced a sharp increase in DCS onset. However, there was not a significant difference in the effects of heavy and mild exercise. Missions conducted by the United States Air Force restrict time of exposure to no more than 30 minutes. The risk beyond 30 minutes exposure rises sharply and

reinforces this upper limit on exposure.

We also conducted some analysis of the database to see if there was any effect of gender on DCS incidence. Both these studies have been submitted for possible publication in the Aviation, Space and Environmental Medicine journal.

5. CONCLUSIONS

We have used survival analysis techniques to develop a model for predicting the risk/ probability of DCS as a function of several risk factors. A stratified model base on the loglogistic distribution seemed to be most appropriate and was found to provide the best fit. We determined that the interaction between exercise and pressure, preoxygenation time, and final altitude were the most significant risk factors. Predictions from this model for different profiles agreed closely with empirical evidence from the database. The validation data helped to sharpen the definitions of exercise and provide an appropriate stratification. The final model will form the basis of the ADRAC, a computer based risk assessment model.

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Appendix

In this appendix, some of the common definitions and terminology used in survival analysis are presented.

Let T denote the time to onset of DCS symptoms. The survival function is defined as

$$S(t) = P(T \geq t),$$

i.e. the probability that the individual does not exhibit any symptoms upto time t. The survival function is a nonincreasing (decreasing) function of time t with the properties that

$$S(0) = 1, \qquad S(\infty) = 0,$$

i.e. the probability of being symptom free for an infinite time is zero.

The Cumulative Distribution Function (cdf) is defined as

$$F(t) = P(T \leq t) = 1 - S(t),$$

the probability that DCS symptoms occur before time t. The Cdf starts at 0 and increases to 1. A steep cdf indicates the rate of survival is low or that onset times are relatively short. A gradual or flat rising graph indicates the time to onset is higher. To obtain an estimate of the survival function or cdf from the available data, we use

$$\hat{F}(t) = \frac{\#\text{ of individuals with symptom onset times less than } t}{\text{total }\#\text{ of individuals}}.$$

Th probability density function (pdf) $f(t)$ of the survival/onset time T is defined as the probability that an individual exhibits DCS symptoms in a small interval per unit time. The cdf and the pdf are related through the following equation

$$F(t) = \int_0^t f(x)dx.$$

The hazard or risk function $r(t)$ specifies the instantaneous rate of developing DCS symptoms at time t, given that the individual has not exhibited any symptoms up till

t. Therefore $r(t)$ can be interpreted as the conditional failure rate. The risk function may increase, decrease, stay constant. or have a more complicated form. The risk function plays an important role in survival analysis because it allows the researcher to develop an appropriate model depending on the progression of the disease. The risk function is defined as

$$r(t) = \frac{f(t)}{S(t)}$$

where $f(t)$ is the probability density function of the onset time as defined before.

The three functions: survival function, probability density function, and the risk function are mathematically equivalent. Given any one, the other two can be derived.

The likelihood equation is given by

$$L(\beta) = \prod_{i=1}^{M} f(t_i) \prod_{j=1}^{N-M} F(t_j)$$

where M is the number of uncensored observations.

When weights are included, the likelihood is proportional to

$$L(\beta) = \prod_{i=1}^{M} [f(t_i)]^{w_i} \prod_{j=1}^{N-M} [F(t_j)]^{w_j}.$$

Associate did not participate in the program.

MODELING AND ANALYSIS OF DISTRIBUTED MISSION TRAINING SYSTEMS: TRAINING EFFECTIVENESS, FLIGHT TRADEOFFS, COSTS, RESOURCE ALLOCATIONS AND AN APPROACH TO DISTRIBUTED TRAINING PROGRAM DEVELOPMENT

Ram Ramesh
Professor of Management Science & Systems

School of Management
State University of New York at Buffalo
Buffalo, NY 14260

Final Report for:
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Mesa, AZ

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Modeling and Analysis of Distributed Mission Training Systems: Training Effectiveness, Flight Tradeoffs, Costs, Resource Allocations and an Approach to Distributed Training Program Development

Ram Ramesh
Department of Management Science & Systems
School of Management, SUNY at Buffalo

Abstract

Distributed Mission Training (DMT) is a revolutionary training paradigm currently evolving at the Department of Defense, especially at the Air force. The fundamental technologies on which DMT is built are: virtual simulation, networked war gaming and intranets. The rationale for DMT is derived from the characteristics of contemporary warfare and the increasing emphasis on creating technology based training environments that realistically capture the complexities and demands of modern military operations. While the dimensions and complexity of modern warfare are expanding, the ability of the defense services to train forces in a realistic environment is being increasingly constrained. The primary constraints arise from limited resources for team skill training using actual equipment such as aircraft, safety limitations of live training events such as air-to-air missiles for instance, and security constraints due to operational conditions. Consequently, DMT is strongly emerging as an alternate but effective mode of team training in the defense services. In this research, we develop models and a spreadsheet decision support system to address the following key questions concerning DMT: (i) *Should DMT be deployed at all, as part of continuation/replacement training programs for F16 crew, (ii) What is the extent to which continuation/replacement training can be conducted using DMT systems, (iii) What are the various system configurations under which DMT can be deployed, (iv) What are the specific costs associated with DMT systems, and (v) Are there specific measures of effectiveness that can they be used to evaluate the potential DMT configurations up front.* Based on our analysis, we develop an approach for the development of future integrated training programs that embed DMT training within a comprehensive framework of other training modalities.

Modeling and Analysis of Distributed Mission Training Systems: Training Effectiveness, Flight Tradeoffs, Costs, Resource Allocations and an Approach to Distributed Training Program Development

Ram Ramesh
Department of Management Science & Systems
School of Management, SUNY at Buffalo

1. Introduction

Distributed Mission Training (DMT) is a revolutionary team training paradigm currently evolving at the Department of Defense, especially at the Airforce. The fundamental technologies on which DMT systems are built are: *virtual reality*, *networks of distributed training systems* and *multimedia communication*. While the United States is pioneering at the cutting edge of these technologies, several other countries such as U.K., France, Israel and the Netherlands are also seriously engaged in such initiatives. The objective of DMT is to concurrently train people in team efforts involving coordination, communication and decision making. The teams may not necessarily be co-located and could be engaged in independent as well as coordinated tasks at remote sites.

The rapid expansions in the dimensions and complexity of contemporary team missions are leading to a tremendous emphasis on the needs for effective, integrated training systems to provide realistic environments for the acquisition of sophisticated and multifaceted team skills. However, such training, while it is rather visionary, is yet to come off age. The primary reasons for this are as follows. First, increasing resource limitations such as the availability of actual equipment for training purposes, costs associated with real world training environments, and safety and security reasons that could forbid mission training in real operating scenarios together severely restrict the scope of live, integrated team training possibilities. Second, team efforts could involve several geographically dispersed individuals operating from different platforms at remote sites, who need to work together in a coordinated manner to achieve the mission objectives. From a practical standpoint it could be either very difficult, or even impossible, to assemble them in a single place to train together. These constraints are especially evident in military training programs, where multiple crews operating diverse units such as aircraft, artillery and ships located at different places need to train, communicate, coordinate and work together to achieve common objectives. Till recently, in the absence of effective integrated training systems, such training is usually conducted in isolated programs in the different services using both the actual equipment and simulated environments. Consequently, the full potential of integrated team training is yet to be realized. In fact, it is

somewhat paradoxical that while people are required to operate as integrated teams in real world situations, the constraints in training do not allow them to practice such missions ahead and prepare for eventual demands.

The answers to these daunting challenges lies in combining three evolving streams of technology: *virtual reality, remote networking* and *multimedia communication*. While many useful applications of virtual reality are fast emerging in diverse areas such as medicine, engineering design, scientific visualization and education, a prima facie area where it is critically needed and has already made a significant impact is *human training*. Training teams of people to coordinate and work together towards a common objective is a big challenge; virtual reality, coupled with powerful image processing and distributed networking technologies, together present a formidable array of technological solutions to this challenge. DMT is a concept that has originated from this perspective, and has evolved into a prototypical technology level that lends to experimentation, analysis and further development.

DMT is based on three principles: (1) teams, and not individuals, execute missions, (2) team skills are built upon, but different from, individual skills, and (3) a combination of the three technology streams could enable creative training opportunities that overcome the limitations of time, distance and training resources. Consequently, DMT is strongly emerging as an alternate but effective mode of team training, especially in the defense services. A large industrial support base consisting of companies engaged in training methodologies and systems, virtual simulation platforms, networking and multimedia database systems is rapidly developing. Additionally, these efforts are also spurring considerable research on team training and the associated technologies at universities, federal laboratories and the industrial sector. Finally, although DMT as a concept has originated from the training needs of the military, it has far reaching implications to team training in numerous other fields as well. Training commercial pilots, air traffic controllers, navigators, instrumentation specialists and assembly line workers all require real-time coordination and communication. The DMT concept provides a powerful framework to develop integrated virtual, constructive and real team training platforms for these applications.

DMT is still very much the state-of-the-art. It is expected to become the state-of-practice in the next millennium. Currently, distributed networks linking several aircraft simulators at each DMT node have been developed and implemented in the airforce. They will be deployed, tested and eventually inducted into their training programs. The current DMT trainer web is a secure intranet hosting virtual and constructive aircraft simulations and other logistics support. Extensive research and development on DMT systems is an ongoing high-priority initiative.

While DMT is a promising technological revolution in the training world, there are also several challenges in the road ahead. Some of the critical questions that remain to be answered are: (1) How and when DMT

should be used as part of a formal training program involving a multitude of team skills and equipment, (2) What are the technological design options and how should DMT systems be configured, (3) What are the current technological and operational limitations of the DMT technologies, and how can they be overcome, and (4) How should DMT systems be developed and implemented in any team training application. These questions lead to an analysis of the potentials and challenges in DMT from three perspectives: *Behavioral, Technological* and *System Implementation*. The critical issues that need to be addressed from these perspectives are summarized in Table 1. In this research, we attempt to find answers to these critical questions. We develop a modeling framework for the training effectiveness, flight tradeoffs between aircraft and DMT, costs and resource allocations and present a proof-of-concept MS Excel based spreadsheet decision support system. The system is illustrated with a model of F-16 DMT systems. However, the modeling framework is general, and can be used to analyze these critical characteristics of DMT systems for any airframe. We conclude the research with a framework and approach for the development of DMT based training programs in general, addressing the behavioral, cognitive and training effectiveness/cost parameters of simulated team training environments.

2. Multi-Modal Integrated Team Training: The Concept

DMT is essentially *the creation of a shared environment which is comprised of real, virtual and constructive systems that allow teams of individuals to train both individually and collectively*. While DMT is primarily a team training concept that has evolved in the Department of Defense for its operational forces, its foundations in terms of training principles and technologies have far reaching implications to the field of human training in general. We present a vision for the emerging DMT landscape and highlight some of the research and development opportunities in this article. The concept of DMT and its potential applications have their roots in the creation of an immersive, fully integrated, seamless information system that connects independent simulation based training environments to operate together. The result is a synergistic, hybrid environment of virtual reality systems in which information is dynamically shared and used among a group of individuals engaged in real-time mission critical activities requiring coordination and communication. Such a hybrid environment would provide significant economies, compared to the cost of moving people and resources in training at the scale of global operations with actual equipment. This concept is particularly relevant to the training programs in the military, where collective training involving several weapon systems, command and control systems and training systems into a seamless global training environment is becoming increasingly critical. This training possibility is envisioned through a seamless integration of real, virtual and constructive domains of operation in a global environment.

The synergistic combination of the three primary domains of DMT can become both the training and the operational backbone of future enterprises, where only their objectives and outcomes differentiate actual

operations and training events. The ***real*** portion consists of the actual operational equipment: in the military context, this will be weapon systems, command and control systems, information, surveillance and reconnaissance assets and the logistical support infrastructure. The ***virtual*** portion consists of the training environment and media, such as equipment simulators, synthetic environments, planning/preview/rehearsal systems; training management systems, distributed and secure connectivity, instructor/operator stations, performance measurement systems and archival capabilities. It can easily be seen that these components could constitute a virtual reality-training environment in any operational setting. The ***constructive*** portion consists of interactive and animated computer-generated models that enrich the training environment by adding desired levels of operational characteristics and complexity. A high level view of the evolving DMT framework is shown in Figure 1.

The training and readiness benefits of DMT will become apparent when these disparate systems are integrated to create an interactive, dynamic environment. This will allow each media to be used independently or synergistically to support all levels of training: individual, procedural and coordinated team training involving high-levels of communication and decision making. In the military context, this can be seen as follows: A real component of DMT consisting of weapon systems will operate in existing airspaces and ranges; a virtual component consisting of simulators conduct training in realistic synthetic renditions of those same areas; constructive computer driven models will provide the training scenarios at both the real virtual levels. Real-time networks provide the connectivity for planning and execution of tasks by players at remote locations. Depending on their objectives, the players will then have the option to operate using their respective actual equipment or simulation components to optimize performance and training effectiveness, and minimize operational risks in live training.

3. Performance Implications

The underpinnings of these new training environments lie in the potential of affordable and effective computational, network and simulation technologies. A suite of core training technologies is rendering this possible. Regardless of the application, the focus of the emerging technologies is to provide individual and team access to mission critical data, accuracy in virtual reality representations of the real world, and coordination mechanisms. With the increasing needs to enhance the quality of communication and decision making in team training, DMT systems are beginning to provide novel capabilities for experimentation and learning. The constructive models of simulation, cue coordination through real-time synchronized imaging systems and online connectivity for both human and model level communications have been prototypically proven. A global training enterprise like DMT could be somewhat expensive. In particular, R&D and procurement represent significant investments. However, the costs for global DMT should not be viewed as totally additive. In fact, if DMT is viewed as a unifying, integrating concept, then significant economies of scale and scope can result from up-front commitments to universally support its implementation. Note

that DMT is viewed as environment integrating real, virtual and constructive domains. Therefore, the already committed investments in the real components of existing training systems do not accrue in DMT costs in totality, except for any reengineering and adaptations to these systems that may be necessary for their integration with the DMT environment. In the military context, the existing weapon systems and command and control systems belong to this category. However, DMT requires additional investments in simulators, training platforms, imaging systems and networking capabilities. In fact, DMT also can be viewed as the next generation virtual and constructive training systems by many organizations when the existing facilities come up for upgrades. Consequently, this could also entail a proration and absorption of some of the DMT costs from existing training capabilities. Furthermore, the core technologies of DMT are nearly universal; they are common to most types of training, education and even entertainment environments. As a result, multiple benefits in different domains of application can be derived from any R&D investment in DMT technologies. Reducing dependence on the actual operating equipment for training by using DMT in conjunction will dramatically lower operating costs while extending the lives of the actual operating systems. Synergistic, hybrid environments could also make training more effective. DMT can create a substantial improvement over current capabilities for a modest increase in cost over what is already being committed for disparate activities. In fact, a common global vision for this integrating concept could conceivably lower the cost for a far superior training capability.

4. Current Research Scope and Objectives

The above issues lay out a broad framework research on DMT systems, DMT based training program development and the field deployment of DMT. While this framework addresses the major strategic decisions in DMT development and application, a full-scale analysis of all the strategic issues and the development of solutions to their underlying problems is beyond our current scope. Therefore, we restrict our research to the following areas in order to develop a proof-of-concept decision support system that can be subsequently extended over the full range of decisions.

- Continuation/replacement training in F16 airframes.
- Assessment of F16 training tasks in terms of their trainability on (i) aircraft only, (ii) DMT only, and (iii) aircraft as well as DMT.
- High level assessment of the critical components of DMT under relevant and important configurations. Broadly, we consider 2-ship and 4-ship DMT systems in this analysis.
- Assessment of the trades from aircraft flying time to DMT flying time that yield the same level of combat mission readiness in tasks that are trainable in both the media.
- Assessment of the training capacities yielded by a set of aircraft and DMT training resources under various strategies jointly utilizing aircraft and DMT together for training.
- High level assessments of the costs associated with the DMT configurations.

- Development of a spreadsheet based parametric sensitivity analysis model to perform (i) aircraft - DMT flying time tradeoff analysis, (ii) Training capacity analysis for joint aircraft - DMT training, and (iii) high level cost analysis of DMT configurations. This model puts all the above analyses together in the framework of a decision support system.

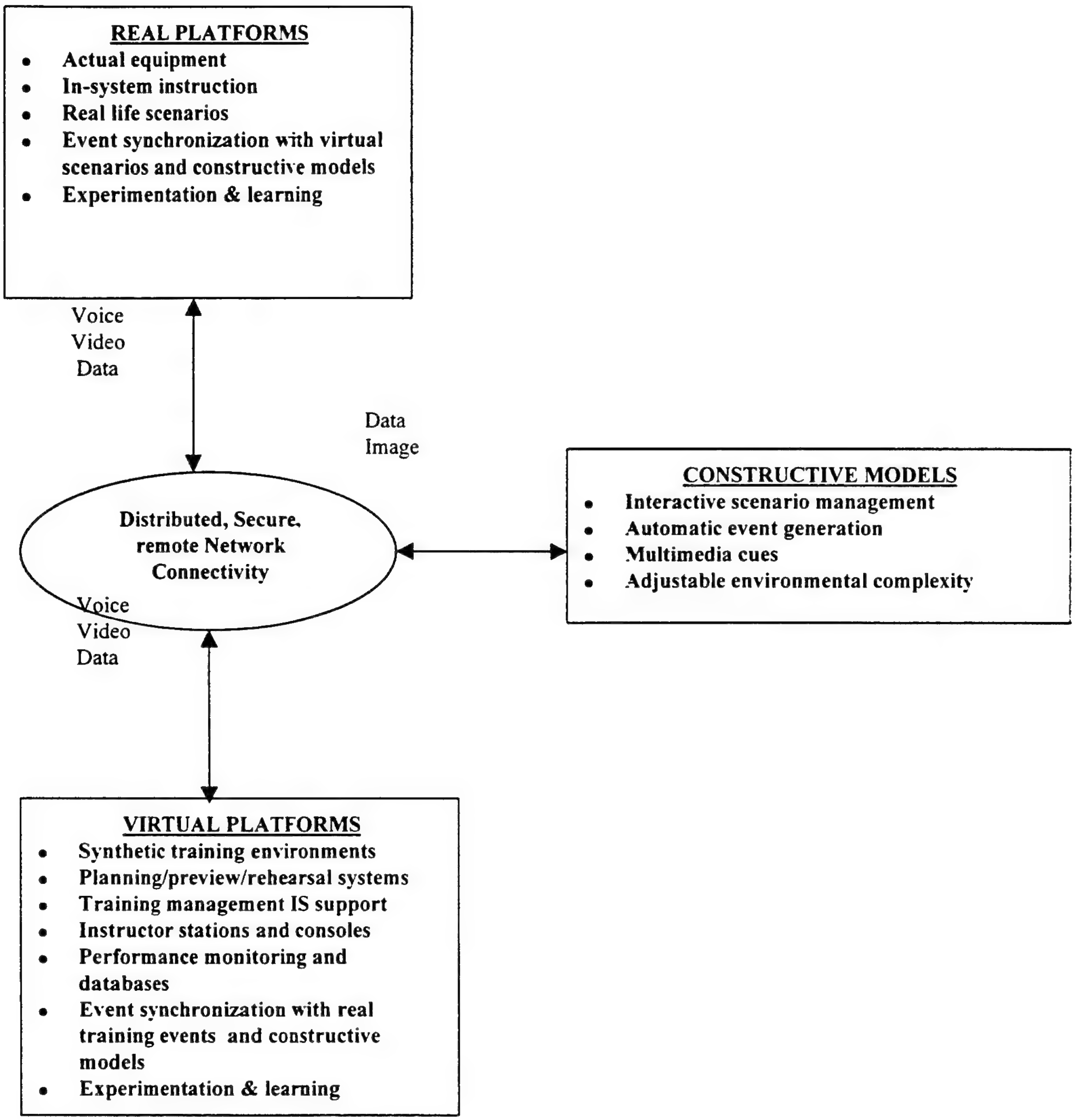

Figure 1. A Framework for DMT Systems

Table 1. Critical DMT Research Questions

- **Behavioral**
  - How do teams work in real world missions?
  - What makes an individual a solid team player?
  - What are the training needs of teams to accomplish their real world mission objectives?
  - How can the virtual, real and constructive modalities of team training be integrated into an effective human-centric training system capable of delivering fully mission-ready team players?
- **Technological**
  - How can integrated training systems be designed? Are their architectural design specifications or industry standards?
  - What is the state-of-the-art, design challenges and emerging solutions in the various components of integrated training systems such as virtual reality platforms, visual systems and networking infrastructures?
- **System Implementation**
  - How are DMT systems configured in practice?
  - What are the modalities of team training in integrated DMT systems and how training scenarios are captured and presented?
  - What is the quality of training realizable from DMT systems? What is the extent to which virtual reality based training could translate to real world missions performance?

5. Research Plan and Methodology

The key research resources utilized in this study are: (i) the DMT expertise available at the Airforce Research Laboratory (ARL), Mesa, AZ, ACC/DO and ACC/DR at Langley Airforce base, and ASC/YW at the Wright Patterson Airforce base, (ii) the four ship DMT prototypical system currently at ARL, Mesa, and (iii) documented sources of information on DMT, distributed training environments at the Airforce, and prior cost benefit studies on multiship training on different airframes (see Moor and Andrews(1992, 1993), Mudd et al. (1997) and Derrick and Davis (1996) among others). The DMT systems are in early stages of their life cycle development, and none have reached the level of field deployment yet. Since most of the information needed in this research occurred in informal domains such as human expertise for instance, we had to rely on the assessments of the numerous subject matter specialists who participated in this study. Accordingly, our research methodology consisted of the following phase of study:

- ***Phase 1:*** Initial data collection on DMT characteristics, training requirements and strategies, and cost/performance indicators. This has been accomplished through a series of interviews with experts at ARL, ACC/DO, ACC/DR and ASC/YW. This phase resulted in a broad framework of the subsequent data collection on the structural details of DMT based training.
- ***Phase 2:*** Refinement of the data collection framework. This involved a series of interviews with the experts at ARL and a detailed study of the literature on cost-benefit studies on multiship as well as single ship simulator training. Putting all these studies together, a systematic and controlled data collection strategy using subject matter experts and the DMT prototype at ARL emerged.
- ***Phase 3:*** The Roadrunner'98 exercises and data collection. ARL conducted these exercises between July 13 - 20, 1998 at Mesa. Several F16 pilots were brought to Mesa to conduct joint war gaming exercises with AWACS and F15 air superiority support using distributed simulation. The four ship F16 DMT at Mesa has been networked with other remote simulation sites, and the war games were conducted as script-controlled scenarios with both constructive and live simulation events in joint exercises. The primary objective of Roadrunner'98 has been to explore the training possibilities with DMT, its training effectiveness as compared to aircraft training, and highlight its strengths and weaknesses that would guide future R&D in this area and its induction into the Airforce training doctrine. Our study has been part of these exercises. Six questionnaires were designed for our study and administered to 15 subject matter experts after they have had significant first hand experience with the DMT systems. The assessments they provided forms a substantial basis for the training effectiveness analyses embedded in te decision support system developed in the next phase.
- ***Phase 4:*** The development of a spreadsheet based decision support system to evaluate the costs and benefits of DMT systems and perform parametrical sensitivity analyses. This system has been developed using MS Excel, and demonstrated to the ARL personnel.

We develop the models underlying the decision support system and its architecture in the following section.

6. The Decision Support System

We present the following details on the elements of the DSS in this section: key elements of the data collected, assumptions underlying the analyses, broad structural details of the models embedded in the system and a summary of the system outputs.

6.1. System Database

The database consists of two components: training effectiveness data and cost data. The effectiveness data has been collected from the six questionnaires used in the Roadrunner study. The questionnaires employ a set of 45 training events in F16 combat training. These events, referred to as *Mission Elements*, have been identified using the F16 RAP and the collective knowledge of the ARL personnel. The key elements of this database are:

- A magnitude scale rating of the mission elements on their importance to combat readiness (Questionnaire 1)
- An evaluation of the training experience with the aircraft to actual combat experience using a 0-4 scale (Questionnaire 2)
- An evaluation of the training experience with 2-ship DMT to actual combat experience using a 0-4 scale (Questionnaire 3)
- An evaluation of the training experience with 4-ship DMT to actual combat experience using a 0-4 scale (Questionnaire 4)
- An evaluation of the minimum number of sorties required for combat readiness of inexperienced pilots when: (i) only the aircraft is used, (ii) aircraft and 2-ship DMT are used, and (iii) aircraft and 4-ship DMT are used. The experts specified the break up between the aircraft and DMT sorties in (ii) and (iii). This questionnaire obtained the tradeoff data between aircraft and DMT sorties in the case of inexperienced pilot training (Questionnaire 5)
- An evaluation of the minimum number of sorties required for combat readiness of experienced pilots when: (i) only the aircraft is used, (ii) aircraft and 2-ship DMT are used, and (iii) aircraft and 4-ship DMT are used. The experts specified the break up between the aircraft and DMT sorties in (ii) and (iii). This questionnaire obtained the tradeoff data between aircraft and DMT sorties in the case of experienced pilot training (Questionnaire 6)

The cost database has been compiled from detailed discussions with the ARL personnel and other relevant data sources available at the laboratory. The key elements of this database are:

- Nonrecurring initial fixed costs
- Long term recurring fixed costs
- Direct operating costs
- Indirect operating costs

Putting training effectiveness and costs together, the models embedded in the system provide a direct cost - benefit analysis of 2-ship and 4-ship DMT systems under various levels of DMT usage.

6.2. Cost-Effectiveness Modeling Assumptions

The following assumptions are made in the development of the various models embedded in the Decision Support System.

1. All mission elements are trainable on the aircraft. However, the effectiveness of aircraft training may vary among the mission elements.
2. It is possible to reach full combat readiness in each mission element by training on the aircraft.

3. The level of combat readiness in a mission element depends on the effectiveness of the training medium (aircraft, in this case). If the training effectiveness of the aircraft in a mission element is low, then the mission element should be practiced a large number of times on the aircraft, in order to reach the full level of combat readiness.
4. No assumptions are made regarding: (i) trainability of mission elements, (ii) ability to reach full combat readiness, and (iii) training effectiveness of DMT. Hence, given the assumptions (1)-(3) on aircraft training, the benefits of these assumptions are fully in favor of the aircraft.
5. Only the training of mission qualified wingmen (inexperienced or experienced) is considered. Training for mission qualification and positional upgrades (flight leads, IP, etc.) are not included in this study, and are intended for future research.
6. No specific resource constraints (such as aircraft, DMT availabilities) are employed in assessing the training requirements. The SMEs have been asked to assess the tradeoffs among the training systems by (i) focusing only on combat readiness, and (ii) ignoring any resource constraints on achieving total combat readiness.
7. The SME evaluations are weighted by the number of flying hours they have put in. The influence of the evaluations of a SME in the final assessments is directly proportional to his flying experience.
8. The learning curve in reaching combat readiness in the mission elements has been taken into account by the SMEs in determining the levels of practice required in the aircraft and the DMT.
9. We recognize the fact that there can be significant variabilities among the pilots in a squadron in terms of their coginitive/psychomotor abilities, aptitude for combat and other flight combat characteristics. We expect these variabilities to be smaller among the experienced pilots than the inexperienced pilots. Further, within a squadron of about 20 pilots, we assume that the training programs will decrease these differences. Consequently, the practice requirements in the mission elements for combat readiness (as specified by the SMEs) are intended for a typical pilot within a squadron, who represents any pilot (experienced or inexperienced, as the case may be) on average.
10. The 45 mission elements considered in this study constitute the bulk of the training that takes place in a typical squadron. There may be mission elements that are not considered here, and either (i) they do not occur frequently, or (ii) if they do, they may be addressed in a future study.
11. All training sorties (on the aircraft or the DMT) are conducted as 4-ship. Accordingly, the SMEs have been asked to treat the training in each mission element as part of 4-ship sorties in responding to the effectiveness/tradeoff questions. Again, the assumption here is that the bulk of the training in a typical squadron is conducted as 4-ship sorties.
12. The bulk of the training events in a typical squadron are captured by the 4-ship sorties involving the 45 mission elements. Deviations from this model, such as red flags (which normally occur once in 2

years) are not considered mainstream training events, and hence are not included in this analysis. However, the differences will even out over a period of training time.

13. The importance of a mission element to combat readiness will depend on where and how a squadron operates. For example, squadrons in Korea and Bosnia could emphasize totally different sets of mission elements in their total training. This emphasis would conform to the Directed Operational Capability (DOC) defined for specific squadrons/wings. However. the differences will even out over a period of training time.
14. The training in mission elements is usually *bundled* into training sorties. A mission element could be practiced as part of *many* different 4-ship training events, and a 4-ship training event could involve *many* mission elements. Hence, the relationships between the mission elements and training events are *many-to-many*.
15. Based on the above assumption, we also assume that the set of practice requirements on the mission elements for combat readiness can be bundled in to a set of 4-ship sortie requirements. Note that the way the training events are designed is dependent on several factors: the instructors and students involved, their existing proficiency levels, resource availability and the commander's prerogatives. Consequently, there will be a tremendous variability among the tasks accomplished among 4-ship events in a squadron. However, we assume that these differences will even out over a period of time, leading to average levels of bundling mission elements into training events.
16. The number of times the mission elements are practiced in the aircraft and DMT will be distributed according to the proportions indicated by the SME data.
17. If the total number of sorties required for combat readiness (as specified by the SMEs) are not available (either in the aircraft or DMT), then whatever is available will be used, and the sorties will be distributed among the mission elements along the lines of the proportionality assumption above.

6.3. Models of Training Effectiveness Analysis

The parameters of training effectiveness analysis that are derived from the Roadrunner questionnaires are as shown in Table 2.

6.3.1. Modeling Objectives

The objectives in the development of the models of training effectiveness are as follows.

- Determine the training effectiveness of the tasks that can be trained on the aircraft, 2-ship DMT and 4-ship DMT, respectively {EFAC, EF2D, EF4D}.
- Determine the minimum practice requirements on the mission elements for combat readiness when: (1) No DMT is available, (2) 2-ship DMT is available. and (3) 4-ship DMT is available.
- Determine these requirements for both inexperienced and experienced pilots {INAC, IN2D_AC, IN2D_2D, IN4D_AC, IN4D_4D, EXAC, EX2D_AC, EX2D_2D, EX4D_AC, and EX4D_4D}.

Table 2. Parameters of Training Effectiveness Analysis

*1. **Task Importance***: IMP(k), k=1,...,45 <Magnitude scale assessment>
*2. **Aircraft Trainability/Effectiveness***: EFAC (k), k=1,...,45 <scale: 0 - 4>
*3. **2-Ship DMT Trainability/Effectiveness***: EF2D (k), k=1,...,45 <scale: 0 - 4>
*4. **4-Ship DMT Trainability/Effectiveness***: EF4D (k), k=1,...,45 <scale: 0 - 4>
5. Comparative Assessment - Inexperienced Pilots:
5.1. No DMT Available:
Aircraft Sorties: INAC (k), k=1,...,45
5.2. 2-Ship DMT Available:
Aircraft Sorties: IN2D_AC (k), k=1,...,45
2-Ship DMT Sorties: IN2D_2D(k), k=1,...,45
5.3. 4-Ship DMT Available:
Aircraft Sorties: IN4D_AC (k), k=1,...,45
4-Ship DMT Sorties: IN4D_4D(k), k=1,...,45
6. Comparative Assessment - Experienced Pilots:
6.1. No DMT Available:
Aircraft Sorties: EXAC (k), k=1,...,45
6.2. 2-Ship DMT Available:
Aircraft Sorties: EX2D_AC (k), k=1,...,45
2-Ship DMT Sorties: EX2D_2D(k), k=1,...,45
6.3. 4-Ship DMT Available:
Aircraft Sorties: EX4D_AC (k), k=1,...,45
4-Ship DMT Sorties: EX4D_4D(k), k=1,...,45

- Model the interrelationships among these parameters and validate (1) consistency among the parametric relationships, and (2) consistency among the evaluating subject matter experts.
- Model overall training effectiveness when: (1) No DMT is available, (2) 2-ship DMT is available, (3) 4-ship DMT is available. Develop measures for:
    - Composite overall training effectiveness for each design of the training systems configuration (No DMT, with 2-ship, with 4-ship)
    - Training effectiveness accruing from each system (aircraft, 2-ship, 4-ship) in each design configuration
    - Differential training effectiveness of each system on tasks that are uniquely trainable only on the individual system concerned. We assume that a 4-ship is a superset of a 2-ship, and hence, there is no differential of 2-ship over 4-ship (that is, all tasks that can be trained on a 2-ship can also be trained on a 4-ship)
        - Aircraft over 2-ship and 2-ship over aircraft
        - Aircraft over 4-ship and 4-ship over aircraft
        - 4-ship over 2-ship

- Model the transfer functions from the aircraft to 2-ship and 4-ship DMTs, and derive the following estimations:
  - Estimation of the transfer functions for the mission elements
  - Estimation of the composite aircraft-DMT transfer curve
  - Estimation of the trainee capacities in each aircraft-DMT joint training configuration
  - Estimation of the level of training that can be accomplished with a training configuration, given resource constraints and training loads
- Develop spreadsheet based decision models for selecting an appropriate training systems configuration, their deployment and usage for a given set of training requirements and loads at a wing.

6.3.2. Modeling Training Effectiveness

We first normalize all SME input data as shown in Table 3. The normalized measures are then averaged over all the SMEs and used in the subsequent models. We introduce some composite measure of training effectiveness using the following definition:

Training effectiveness on a mission element = {Mission element importance}{Proportion of sorties required on the training system for the mission element}{Training effectiveness of the training system for the mission element}

Using this model, we define the following training effectiveness measures:

- **No-DMT-Available:** $AC\_EFF = \Sigma\{IMP(k)\}\{INAC\%(k)+EXAC\%(k)\}\{EFAC(k)\}$
- **2-Ship-DMT-Available:**$AC\_2S\_EFF=\Sigma[\{IMP(k)\}\{IN2D\_AC\%(k)+EX2D\_AC\%(k)\}\{EFAC(k)\}]+[\{IMP(k)\}\{IN2D\_2D\%(k)+EX2D\_2D\%(k)\}\{EF2D(k)\}]$
- **4-Ship-DMT-Available:**$AC\_4S\_EFF= \Sigma [\{IMP(k)\}\{IN4D\_AC\%(k)+EX4D\_AC\%(k)\}\{EFAC(k)\}]+[\{IMP(k)\}\{IN4D\_4D\%(k)+EX4D\_4D\%(k)\}\{EF4D(k)\}]$

The training effectiveness accruing from each system in each of the above configurations can be directly obtained from the individual components in the respective equations. We now introduce measures of differential training effectiveness among the training systems as follows.

- **Aircraft and 2-ship DMT**
  - $AC\text{-}2SHIP = \Sigma\{\{IMP(k)\{EFAC(k)\text{-}EF2D(k)\}: EFAC(k) > EF2D(k)\}$
  - $2SHIP\text{-}AC = \Sigma\{\{IMP(k)\{EF2D(k)\text{-}EFAC(k)\}: EF2D(k) > EFAC(k)\}$
- **Aircraft and 4-ship DMT**
  - $AC\text{-}4SHIP = \Sigma\{\{IMP(k)\{EFAC(k)\text{-}EF4D(k)\}: EFAC(k) > EF4D(k)\}$
  - $4SHIP\text{-}AC = \Sigma\{\{IMP(k)\{EF4D(k)\text{-}EFAC(k)\}: EF4D(k) > EFAC(k)\}$
- **2-ship and 4-ship DMT**
  - $4SHIP\text{-}2SHIP = \Sigma\{IMP(k)\{EF4D(k)\text{-}EF2D(k)\}\}$

Table 3. Normalized Measures

$$IMP(k) = IMP(k)/[Max\{IMP(k)\}], \ k=1,\ldots,45$$

$$EFAC(k) = EFAC(k)/5, \ k=1,\ldots,45$$
$$EF2D(k) = EF2D(k)/5, \ k=1,\ldots,45$$
$$EF4D(k) = EF4D(k)/5, \ k=1,\ldots,45$$

TOTAL_INAC = ΣINAC(k)
TOTAL_IN2D_AC = ΣIN2D_AC(k)
TOTAL_IN4D_AC = ΣIN4D_AC(k)
TOTAL_IN2D_2D = ΣIN2D_2D(k)
TOTAL_IN4D_4D = ΣIN4D_4D(k)

TOTAL_EXAC = ΣEXAC(k)
TOTAL_EX2D_AC = ΣEX2D_AC(k)
TOTAL_EX4D_AC = ΣEX4D_AC(k)
TOTAL_EX2D_2D = ΣEX2D_2D(k)
TOTAL_EX4D_4D = ΣEX4D_4D(k)

INAC%(k) = INAC(k) /TOTAL_INAC

IN2D_AC%(k) =IN2D_AC(k)/TOTAL_IN2D_AC
IN2D_2D%(k) =IN2D_2D(k)/TOTAL_IN2D_2D
IN4D_AC%(k) =IN4D_AC(k)/TOTAL_IN4D_AC
IN4D_4D%(k) =IN4D_4D(k)/TOTAL_IN4D_4D

EXAC%(k) = EXAC(k) /TOTAL_EXAC

EX2D_AC%(k) =EX2D_AC(k)/TOTAL_EX2D_AC
EX2D_2D%(k) =EX2D_2D(k)/TOTAL_EX2D_2D
EX4D_AC%(k) =EX4D_AC(k)/TOTAL_EX4D_AC
EX4D_4D%(k) =EX4D_4D(k)/TOTAL_EX4D_4D

6.3.2.1. Transfer of Training Estimation by Mission Elements

Consider a mission element k. Without loss of generality, we will use the following generalized notations in describing the transfer of training models:

AC(k) = # of aircraft sorties needed if no DMT is available.

D_AC(k) = # of aircraft sorties needed if a DMT is also used

D_D(k) = # of DMT sorties needed

In this notation, we have suppressed (1) the types of DMT and (2) types of training (inexperienced/experienced) in the above notation for simplicity. The four categories of training configurations (IN/2SHIP, IN/4SHIP, EX/2SHIP, EX/4SHIP) by replacing these generic parameters with their respective parameters in the following models.

We model the transfer of training using two dimensions: # of aircraft sorties and # of Sim sorties. We have two points on this transfer curve from the SME data as follows: (0, AC(k)) and (D_D(k), D_AC(k)). We denote the point (0, AC(k)) as the case where *no DMT is used*, and the point (D_D(k), D_AC(k)) as *the limiting case of DMT use as specified by the SMEs*. We assume the commonly used exponential transfer function (see Bickley []). The exponential function has been very well studied in the literature, and has been in wide use in the training area. The transfer function in this case is modeled as $y = Ae^{-Bx}+C$, where

x = # of Sim sorties

y = # of aircraft sorties

A, B, C = transfer function constants

Using the two points along this curve available from the SME data and the transfer effectiveness of aircraft (EFAC(k)) determined from the SMEs earlier, we determine A, B and C as follows.

$A_k = \{EFAC(k)\}\{AC(k)\}$

$C_k = \{1-EFAC(k)\}\{AC(k)\}$

Now, plugging in the other SME point $\{x = D\_D(k),\ y = D\_AC(k)\}$ on the transfer curve, we get B_k as:

$B_k = -\{1/D\_D(k)\}\{\ln[\{1/EFAC(k)\}\{(D\_AC(k)/AC(k))+EFAC(k)-1\}]\}$. For the sake of simplicity, we will denote the transfer curve for mission element k as: $y_k = A_k e^{-B_k x_k} + C_k$.

6.3.2.2. Composite {Aircraft, DMT} Transfer of Training Estimation

We now turn our attention to the determination of an *overall transfer curve*: from total number of aircraft sorties to total number of DMT sorties, putting all the missions together. Clearly, this is a very complex issue, as (1) many mission elements could be performed in a mission sortie, and (2) a mission element could be needed in many missions. However, from the point of view of *estimation*, we assume that the number of sorties indicated by the SMEs in each category represent the approximate proportion of the time a pilot is required to spend in each mission element during training for combat ready preparation. Consequently, we deal with the normalized percentage values of the sorties requirements in the following analysis.

Consider a two dimensional plot of normalized total aircraft sorties time versus normalized total DMT time. We approximate sorties data for time, as the analysis is considered for a long run period such as a year. Consider any training system configuration with x(k) and y(k) sorties used for mission element k on the DMT and aircraft, respectively. These two parameters are the same as those defined in the transfer curve estimation above. Let TY denote the ratio of the total time actually spent in aircraft training when DMT is used to the total time when no DMT is used. Similarly, let TX denote the ratio of the total time actually spent in DMT training when DMT is used to the total time when DMT is used in the limiting case as specified by the SMEs. Using this, we define TY and TX as $TY = \Sigma y(k)/\Sigma AC(k)$ and $TX = \Sigma x(k)/\Sigma D\_D(k)$. When TX = 0, the value of TY = 1. This corresponds to the case where no DMT is used.

Similarly, when TX = 1, TY = ΣD_AC(k)/ ΣAC(k). This corresponds to the limiting case of DMT use as specified by the SMEs. Hence, TX and TY range between 0 and 1 in this normalized plot. For any value of TX between 0 and 1, we can determine the corresponding total aircraft time required (TY) from the individual transfer functions developed in the above analysis. However, we can get into a serious combinatorial problem leading to inconsistencies in estimating the total times when they are *assembled* from individual mission element transfer functions. Hence, we suggest the following procedure to systematically capture the tradeoffs. First, starting from (TX=0, TY=1), consider transfers from aircraft to DMT in steps of P%. For instance, the first point on this curve is aggregated from a decrease in aircraft time in **all** the mission elements by P% of the difference between the maximum and minimum aircraft practice requirements specified by the SMEs {AC(k)-D_AC(k)}. Continue this as far as possible. Finally, join all the points thus generated with a smooth curve. We call this transfer curve as a ***P% step reduction curve***, as this stepwise reduction is universally applied to all the mission elements. Clearly, there are numerous other ways to effect these transfers, and each transfer would produce a curve. Such combinations can best be analyzed using a spreadsheet. The P% points on the normalized plot are determined by the following procedure.

1. Select P% (say around 20%). Set n =1.
2. y(k, nP%) = AC(k) - (nP){AC(k)-D_AC(k)}, k = 1,...,45
3. x(k, nP%) = $\{-1/B_k\}\ln\{(y(k,nP\%) - C_k)/A_k\}$, k=1,...,45
4. Calculate TX(nP%) and TY(nP%) from the above definitions.
5. If y(k, nP%) $\leq$ D_AC(k) stop. Else go to step 6.
6. Set n = n+1. Return to step 2.

After obtaining the set of points (TX,TY) from this procedure, plot them on the unit quadrant, and join by a smooth curve. Recall that (1) many mission elements could be performed in a mission sortie, and (2) a mission element could be needed in many missions. Therefore, the estimation of the actual sorties requirement for a given trainee load and training requirements from the data we have is rather difficult. However, we can estimate lower bounds on the number of pilots that can be trained using the existing aircraft and DMT resources over a period of time, say a year. Then using a *mission element bundling* concept, we can derive a sensitivity analysis on the estimated sorties requirements. This analysis is developed as follows.

6.3.2.3. Aircraft/DMT Trainee Capacity Estimation

Let N_AC and N_D denote the number of aircraft and DMT sorties available in a year for training. To begin with, we make the following assumptions:

1. All aircraft sorties are flown as 4-ship, in order to establish a common basis for our comparative analysis.

2. The number of times the mission elements are performed in the aircraft and DMT will be distributed according to the proportions indicated by the SME data.
3. If the total number of sorties required for combat readiness (as specified by the SMEs) are not available (either in the aircraft or DMT), then whatever is available will be used, and the sorties will be distributed among the missions along the proportionality assumption above.
4. The set of sortie requirements on the mission elements can be *bundled* into a set of sortie requirements on missions.

Now, based on assumptions 3 and 4, we introduce two parameters as follows:

- An **aircraft sortie reduction factor** δ_a which ranges between 0 and 1, indicating the level to which the required total number of aircraft sorties for a given training load that can be accomplished with the available number of aircraft sorties.
- A **DMT sortie reduction factor** δ_s which ranges between 0 and 1, indicating the level to which the required total number of DMT sorties for a given training load that can be accomplished with the available number of DMT sorties.
- A **mission element bundling factor** γ which ranges between 0 and 1, indicating the proportion of the total number of mission element rehearsals that can be *bundled* into mission sorties. For example, if 1000 mission element rehearsals in total are required for combat readiness, and if these can be organized into 800 mission sorties (by fitting many mission elements into a mission sortie), then the bundling factor $\gamma = 0.8$.

Using the above, we can now determine the minimum number of pilots that can be trained for a given training system configuration as follows. Let NTY = TY{ΣAC(k)} denote the actual number of aircraft sorties required in a training system configuration. Similarly, let NTX = TX{ΣD_D(k)} denote the actual number of sim sorties required. Therefore, we have: MIN_PILOTS_AC = N_AC/{NTY*δ_a*γ} and MIN_PILOTS_D = N_D/{NTX*δ_s*γ}.

MIN_PILOTS_AC and MIN_PILOTS_D denote the minimum number of pilots that can be trained with the available aircraft and DMT resources respectively, for given levels of the sortie reduction and mission bundling factors. Also, if NTY(γ)< N_AC, then we can simply set δ_a= 1. Similarly, if NTX(γ)< N_D, then we can simply set δ_s = 1. These cases represent situations where the available sorties exceed the training requirements (rare!). We need the reduction factors only when these resources are not adequately available. Further: N_AC = {# of aircrafts available}{# of sorties per aircraft per year} and N_D is computed for 2-ship and 4-ship DMTs as follows: N_2D = 2{# of 2-ship DMTs available}{# of sorties per DMT per year} And N_4D = 4{# of 4-ship DMTs available}{# of sorties per DMT per year}.

6.3.2.4. Training Level Estimation

This analysis is the converse of the capacity estimation model. In this case, we fix the available resources (such as aircraft and DMT) and estimate the level of practice in the mission elements that can be accomplished if we need to train a give set of pilots in the inexperienced and experienced categories. We summarize this analysis as follows.

SME INPUTS

- SME assessments IMP, EFAC, INAC, IN2D_AC, IN2D_2D, IN4D_AC, IN4D_4D, EX2D_AC, EX2D_2D, EX4D_AC, EX4D_4D
- Transfer functions: $y_k = A_k e^{-B_k x_k} + C_k$, where y_k = {# of A C sorties in mission element k}, x_k = {# of DMT sorties in mission element k}
- Composite Transfer function: TY(P%) = f(TX(P%)), where P% is the step parameter used in the construction of the composite transfer function.

USER INPUTS

- NPILOTS : Number of pilots to be trained in a year
- NUM_AC : Number of Aircraft available
- AC_SORT: Number of available sorties/aircraft
- NUM_D : Number of DMTs available
- D_SORT: Number of available sorties/DMT
- γ : Mission bundling factor (between 0 and 1), determined from training program
- n : the number of P% reductions in aircraft time to be employed in selecting an aircraft sim training system configuration.

DECISION PARAMETERS

- δ_a and δ_s: These parameters measure the extent to which the required level of training can be fulfilled under the conditions specified in the user specified parametric settings.
- **δ_a = {NUM_AC}{AC_SORT}/[{NPILOTS}{TY(nP%)}{ΣAC(k)}{γ}**
- **δ_s = {NUM_D{D_SORT}/[{NPILOTS}{TX(nP%)}{ ΣD_D(k)}{γ}**

In this analysis, the following parametric sensitivity characteristics are important:

1. As n increases (greater use of DMT and less use of aircraft):
    - TY(nP%) decreases (proportion of aircraft sorties)
    - TX(nP%) increases (proportion of sim sorties)
    - Consequently, δ_a increases (the level to which the required aircraft sorties can be fulfilled with the available aircraft sorties)
    - Hence, δ_s decreases (the level to which the required sim sorties can be fulfilled with the available sim sorties)
2. As γ increases (greater bundling leading to fewer sorties to accomplish all training)

- Both δ_a and δ_s decrease. This indicates that the better we are able to bundle the mission element rehearsals into missions, the greater will be the level to which we can satisfy the sortie requirements for combat readiness, within the available resources.

3. As NUM_AC and/or AC_SORT increase:
   - δ_a increases. This is an expected result. BY increasing the resource levels. we can better satisfy the training requirements.
4. As NUM_D and/or D_SORT increase:
   - δ_s increases. This is an expected result. BY increasing the resource levels. we can better satisfy the training requirements. This result is the same as in the case of the aircraft above.
5. As NPILOTS increases:
   - Both δ_a and δ_s decrease. This indicates that greater the training load, the smaller the degrees to which we can train each pilot on both the aircraft and DMT. given the resource restrictions.

Finally, if the user wishes to modify the basic SME assessments. he can do so. In this case, the entire analysis, starting from the determination of the transfer functions and the composite function will be repeated with the new set of base data that the user might provide. We anticipate this analysis in practice, as there may be users who may not fully agree with the SME assessments. However, we envision only minor changes to the basic SME data from the users. The overall training effectiveness modeling strategy is summarized in Figure 2.

6.4. Modeling Costs

The costs associated with DMT systems are modeled in terms of recurring and nonrecurring acquisition costs, and direct and indirect operational costs over a time horizon. The nonrecurring acquisition costs include the physical facilities such as training center and database development center. The recurring acquisition costs include simulator hardware and software, IOS. brief/debrief facilities, visual systems, network systems, DMT control station, DMT threat system, DMT data logger system and other software support. These broad components are detailed into specific items in the spreadsheet model. The direct costs include instructional costs and the administration of the training center and database center. The indirect costs pertain to the overheads on training and management. The costs associated with each configuration of DMT systems have been compiled in the spreadsheet. The decision support component of the spreadsheet enables a user to specify the desired levels of practice in aircraft and DMT sorties. training loads, aircraft and DMT resources available and the configuration of the training program in terms of aircraft and DMT sorties to be used. The spreadsheet model estimates the annual prorated costs by taking into account the extensions to aircraft lives due to the reduction in aircraft sorties due to the introduction of DMT in the training environment. The net cash flows over a 15 year period are determined from this analysis, and a net present value of them is calculated at an user specified interest rate. The analyses show a

significant positive net present value of the cash flows over this period, which substantially justifies the investments in DMT systems.

6.5. System Architecture

The decision support system has been developed in MS Excel 7.0. The system consists of the following series of linked and integrated worksheets:

- **QUEST1, QUEST2, QUEST3, QUEST4, QUEST5, QUEST6:** These worksheets contain the primary SME data collected from Roadrunner'98, and the data processed from it to generate inputs for the decision support system
- **INPUTS:** This worksheet presents the processed data input from the primary SME data
- **TRANSFERS:** This worksheet calculates the transfer of training functions
- **2SHIP, 4SHIP:** These worksheets perform the parametric sensitivity analyses on the tradeoffs. sortie requirements and composite transfer estimations for training with 2-ship and 4-ship DMT respectively, in conjunction with aircraft.
- **CAPACITY:** This worksheet performs parametric sensitivity analyses on the training capacities of various training system configurations using a *user guided test drive* approach.
- **TR_LEVELS:** This worksheet performs parametric sensitivity analyses on the training levels of various training system configurations for a given set of training loads and training resources available using a *user guided test drive* approach.
- **EFFECTIVENESS:** This worksheet presents the differential transfer effectiveness among aircraft, 2-ship and 4-ship DMT systems using graphical displays.
- **ACQ_COSTS_NR, ACQ_COSTS_RR:** These spreadsheets capture and analyze the nonrecurring and recurring acquisition costs associated with each DMT configuration.
- **DIRECT_COSTS, INDIRECT_COSTS:** These spreadsheets capture and analyze the direct and indirect operational costs associated with each DMT configuration.
- **COST_ANALYSIS:** This worksheet performs the parametric sensitivity analyses on the costs by taking into account all the cost elements and training strategies for each DMT configuration using a *user guided test drive* approach.

The worksheets are sequentially linked. Hence, a user could perform an analysis in a worksheet by changing the parameters in any of the preceding worksheets. The worksheet INPUTS which contains the fundamental processed SME assessments, serves as the root of this sequence. A high-level architecture of this system and an illustrative final analysis are presented in the appendix.

7. Conclusions from the System

In summary, this research has yielded the following cost - effectiveness assessments leading to a spreadsheet based decision support system for DMT training system evaluation:

- A quantitative comparative training effectiveness analysis of the three training system configurations (No DMT, With 2-Ship DMT, With 4-Ship DMT)
- A quantitative assessment of the effects of training task importance and training effectiveness of the three training systems on the sorties required on these systems for combat readiness under the three configurations.
- A quantitative assessment of the differential training characteristics of the three training systems.
- Estimation of the transfer functions for the mission elements. the composite aircraft-DMT transfer curve, the trainee capacities in each configuration and the costs associated with DMT systems
- Estimation of An overall decision support system for the selection and parametric sensitivity analyses of the various training and cost parameters.

8. An Approach to Training Program Development

The advances in computing and communication technologies have led to synthetic training environments with tremendous potential. Distributed Mission Training (DMT) is such an environment that has adaptively focussed and integrated virtual reality and networking technologies for team training in dynamic operational environments. Intra and inter team communication, coordination and decision making in such environments are central to mission critical team performance. While these attributes are especially significant in military operations, they define effective teamwork in general, ranging from sports and entertainment to production and service environments. The approach presented in the following analysis is based on the development of concepts, tools and ideas presented in Ramesh and Andrews (1999).

The concept of DMT has been technologically demonstrated in defense operations. Equipped with advanced image generation technologies. high resolution displays and secure distributed networks, DMT systems connect a wide variety of local and geographically dispersed virtual training platforms for mission critical team training. Further, DMT technologies provide extremely high levels of both physical and functional fidelity in team training. The resulting real-time virtual training networks include aircraft simulations and other simulated systems such as tanks and ships. In addition, these platforms can be linked to real training equipment, thus offering the potential for synthetic environments that will support training at the individual. team, and joint service levels. As a result of these increased capabilities, combined with significant reductions in costs, the training and technology development communities are greatly expanding their use of synthetic virtual training environments.

However, there are still formidable challenges in the implementation of these systems. This is because, training is substantially more than putting hardware and software systems to work together. It involves managing people's experiences in training so that they will have a greater potential for accomplishing real life missions than before. Indeed, training is a systemic phenomenon. The development and implementation of instructional systems (Dick & Carey, 1990) follows the general principles of systems

engineering in that it involves mission analysis, identification of system inputs and outputs, and allocation of functions to various system components. Based on this concept simulators are merely subsystems or components of the overall training system. Consequently, it is necessary to ask whether or not these components are functioning correctly and generating the proper outputs. This leads to the following key question in the design and implementation of DMT: *Does the integration of DMT technologies into a training system materially improve the likelihood that those who use DMT will successfully accomplish their missions?* This section examines this critical question. In particular, we address: (1) the training challenges for which DMT systems are meant for, (2) existing empirical and analytical data that give us cause for optimism. (3) some design considerations for DMT systems, and (4) the major cultural changes that must take place in the way organizations view training so that DMT can have the largest possible impact.

8.1. Team Training : A Naturalistic Paradigm

A naturalistic perspective on training is to view the process and its effectiveness from the *way people use their experience to analyze, interact and make decisions in field settings* (Klein *et al.* 1993). This is dramatically different from the traditional ways of analysis in the sense that emphasis is placed on how trainees are concerned about sizing up a situation and refreshing their situational awareness through feedback, rather than reacting to environmental stimuli and their demands. The contextual factors that affect the way real world operations occur are central to this analysis, and are summarized in Table 4. A central theme that emerges from an analysis of training processes from this perspective is: *decision making from situational awareness and assessment, prioritization in dynamic task environments and action/feedback structures in event management.* Individuals operating collectively in mission-critical, task-oriented environments are in essence *decision makers*, who together determine the final outcome of a mission. So, the naturalistic perspective requires an investigation of what makes them effective decision makers. Once established, these attributes can be used to specify which knowledge, skills and processes must be trained on in order to achieve targeted performance. Table 5 presents a summary of attributes of an effective decision maker operating within the context of a team and its goals.

Table 4. Contextual Factors in Real World Operations

- How ill structured are the problems encountered in operational settings
- How uncertain and dynamic are the operational environments
- How irregular and shifting are the operational goals over time
- How action feedback loops govern operational strategies
- How stressful are the tasks in terms of time and effort required
- How high are the stakes in operational decision making
- How many players are involved in an action plan and how do they interact
- How do the operational goals conform to organizational norms and objectives

Table 5. Attributes of Effective Performers in Team Contexts

- Flexibility: Ability to cope with environments that are ambiguous, rapidly changing and complex.
- Speed: Ability to make rapid decisions, often in the face of severe consequences.
- Resilience: Ability to operate ambiguous, uncertain, stressful and high stakes environments without suffering degradations in performance.
- Adaptivity: Ability to recognize when and how to apply an action strategy and when to change or modify the strategy with problem demands.
- Risk Management: Ability to quickly assess the risks in various courses of action, weigh the consequences and payoffs.
- Accuracy: Ability to state accurately what is obvious; quick and deep understanding and effective communication.

The objective of any team training enterprise is to develop individuals well trained to a desirable level of expertise in these attributes. This translates to a training focus on the major areas shown in Table 6. The above analysis clearly points to what to train individuals on, when it comes to mission-critical team performance. First, context-specific domain knowledge is crucial. Next, a set of cognitive processes and skills need to be focussed on (see Table 6). Finally, the psychomotor skills required in the operational settings need to be emphasized. Focusing appropriately on these facets in a training program would accelerate the acquisition of proficiency, learning and organizing domain knowledge that supports complex team maneuvers, and the ultimate objective of achieving a desired level of expertise in both individual tasks and team missions. Team training based on a combination of the principles of virtual reality and real time concurrent connectivity among remote players addresses these facets and at the same time appears to overcome most of the practical limitations of time and space in a meaningful training environment. While concurrent connectivity is necessary in team training scenarios, the role of virtual reality as a training medium has been a subject of great discussion among researchers. We take the position that virtual reality is indeed an effective medium and present the following line of reasoning. First, simulated training environments can significantly accelerate proficiency by exposing trainees to the kind of situations they are likely to encounter in the real world, but which could be hazardous or very expensive to practice in actual operational settings. For example, in training air force pilots in mission combats, shooting an enemy aircraft can never be practiced with real aircraft exactly the same as they would encounter in an actual situation. Second, simulations can be controlled - the characteristics of the training scenarios, situational cues and decision outcomes can be provided as aids in the development of situational awareness, pattern recognition and template building. The constructive models, which play a crucial role in DMT systems, are intended for this purpose. Finally, simulations are also an effective means to train reasoning skills, metacognitive skills, risk-assessment skills and communication skills without the overhead and complexities of real world training. The above analysis, while highlighting the needs of team training from a naturalistic perspective, also raises the following research questions regarding the training effectiveness of concurrently connected virtual reality environments like DMT:

- On what basis do trainees perceive similarity in training situations? What triggers a template in human memory, how do people seek additional information, learn from other co-trainees and exchange data?
- How can the virtual training components be integrated with real training components to provide comprehensive training effectiveness?
- In knowledge-rich training environments, how should the knowledge be organized into virtual training modules such that it fosters ready access to information when necessary?
- How can the quality of training in virtual platforms be evaluated? For example, how do we know when someone becomes an expert?

These are open questions, yielding a rich research agenda. We summarize the lessons learned from our experience with virtual reality platforms, and highlight the critical training effectiveness research issues specific to DMT in the following discussion.

Table 6. Major Skill Areas in Effective Team training

- Organized knowledge structures: Knowledge templates. relationships and triggers
- Situation assessment skills: Make rapid, accurate assessments of situations; cue/pattern recognition and assessment of their significance
- Metacognitive skills: Select strategies, modulate strategies as problems unfold, engage in effective resource management, self-assess and adjust as necessary
- Reasoning skills: Analogical and causal reasoning, creative problem solving
- Domain-specific problem solving skills: Integration of domain knowledge with the other skills leading to rapid problem solving
- Mental simulation skills: Know when to simulate a scenario mentally and use it to evaluate strategies for novel problems
- Communication skills: Brevity, clarity and timeliness of communication - both one-on-one and groups
- Other psychomotor skills: Specific to a training scenario.

8.2. Lessons from History

Although there have been a number of efforts involving large scale simulation for analysis, development. and training (Parsons. 1972), most of this early research focused on command and control systems. Recently, there has been a substantial research thrust on identifying team skills and developing techniques for training those team skills (Salas and Cannon-Bowers. 1997; Salas, Dickinson, Converse and Tannenbaum, 1992). These works have identified several training strategies such as guided practice and cross-training for instance, that can be effectively exploited in DMT systems. However, very little of this research has been applied to designing training for the high-performance team skills typical to DMT. The earliest virtual platform training programs involved flight simulators. and concentrated mainly on training basic procedural and psycho-motor skills. By the mid 1980's, however, technology advanced to the point that it was possible to interconnect simulators and conduct team training. The first example of such training was the SIMNET project in which a number of tank simulators were interconnected to provide collective training (Alluisi. 1991). Subsequently, several studies on team training pilots on virtual platforms have

been carried out. Principal among these are: networked F15 virtual platforms study at McDonald Aircraft Company (Houck *et al.*, 1991), Multi-service Distributed Training Testbed (MDT2) (Dwyer *et al.* 1995) and the Roadrunner'98 study of networked DMT systems (see Crane, 1999, in this issue). In all these studies, a full spectrum of simulated team missions were carried out. Teams performed their normal mission planning and post-mission analyses. A qualified instructor monitored the training scenarios and provided additional guidance to the teams. Training effectiveness research data collected from these experiments examined both process and product measures. Process measures pertain to the frequency and quality of communication, mutual support and decision making. Product measures pertain to numerical assessments of performance. In addition, each pilot underwent extensive interviews to determine how well they thought the training experience prepared them compared to their normal team training in their actual equipment. The results were quite positive. In all cases the pilots showed considerable improvement on both the process and product measures from the first day of training to the last day. The probability of successfully completing a mission improved significantly during the training week. Perhaps even more encouraging were the interviews that showed that people were generally quite positive about the experience. It is important to stress how seldom these teams are able to not only train together on a consistent basis but also be able to plan and analyze missions together. When training with actual equipment, the physical distances that separate individual players when the exercise is over make it difficult to have such sessions. As a result, even though each of the individual service teams was proficient at its part of the mission. they had very little opportunity to integrate their skills with the other members and work those skills in a realistic tactical environment. All these studies show that it is possible to cross train using DMT with multiple virtual platforms in a single training package linked over distances to produce an effective composite training environment.

8.3. DMT Design Considerations

The above studies indicate that DMT offers the potential to be a significant training tool. Based on the data gathered thus far, and faced with the increasing pressure to reduce training costs and improve trainee skills, DMT appears to be a cost-effective training approach. Networkable, high-fidelity DMT systems encompassing a wide range of virtual training platforms are fast emerging, and are most likely to dominate the training landscape of the next millennium. However despite the current enthusiasm for DMT, a variety of significant challenges in achieving the desired training effectiveness still remain. We examine some of these issues from the point of view of human-centric and naturalistic systems design as follows.

8.3.1. Skill Acquisition, Retention, and Transfer

Clearly the intent in developing DMT systems is to provide additional opportunities for individuals to acquire and maintain job relevant skills. There is a great deal of basic research on skill acquisition and decay which can be used as a starting point for identifying those factors that influence skill acquisition and

retention (Patrick, 1992). There is, however, very little data that describes how complex skills are acquired and maintained in real world work settings (Welford. 1968). Further, almost no research involving a detailed examination of how continuation or field training experiences, as opposed to formal institutional or schoolhouse training, impacts the development of a skilled team player. A well-structured plan of research is required to understand the development and retention of high performance skills. The results of such research could then be used to define the training strategies and types of experiences necessary to maintain the training readiness of teams in general. There is very little evidence regarding the transfer of skills from virtual platforms to the actual equipment (Bell & Waag. 1998). Although significant improvements have been repeatedly claimed using both outcome and process measures, almost no empirical evidence is available regarding the degree to which the knowledge, attitudes, and skills learned or enhanced in virtual platforms transfer to actual mission performance. This absence of transfer data is not unique to DMT. Goldstein (1986) observes that very few training programs include a systematic evaluation of their effectiveness. Such evaluations are usually difficult to conduct. Bolcovici (1987) has described some of the factors and the problems involved in attempting transfer of training studies within the military. Although transfer of training research is difficult to accomplish, it is essential to validate the benefits that can be derived from DMT. Specific studies on transfer of training from DMT systems to real world performance are needed. Without appropriate transfer of training data, we are left in a situation similar to that encountered by many college students: one may be capable of passing the exams within a class but not be able to apply the skills and knowledge acquired in that class in other courses. In addition, transfer of training experiments provide a means of determining which variables in a virtual training system have the greatest impact on the quality of training yielded by that system. Such information is invaluable in deciding between alternative system configurations and developing the most cost-effective training systems. Finally, critical to the development and interpretation of research involving skill acquisition, retention, and transfer is the need to develop measures of individual and team performance that are most appropriate for the complex high performance skills characteristic of DMT environments. Without such measures, it is difficult to develop valid training metrics. validate fidelity requirements, or determine training needs.

8.3.2. Instructional Features

Even if it were possible to create a synthetic environment that fully replicated the real world, it is not necessarily the case that such a design would represent an optimal training environment. Indeed, if the focus is on merely recreating reality in a digital world, it is quite possible that a suboptimal training environment is created. Such a possibility would result from failures in considering: (1) the constraints and training possibilities of hardware and software tools, and (2) the strategies and tactics for using those tools that would allow greater training efficiencies than that are currently possible in the real world. DMT represents a quantum leap in the complexity of simulation-based training. As such it involves a shift from

direct control of an individual learning psychomotor and procedural skills to indirect control of large numbers of individuals executing complex hierarchically nested sequences of psychomotor, procedural, cognitive, and team skills in fluid. rapidly changing environments. This new training environment, in which the instructor may be much more likely to be involved in process and supervisory control of training activities rather than one on one instruction, demands a human-centered design approach that targets hardware and software designs to meet user needs. Table 7 presents a set of critical design questions that must be well considered in this process.

8.3.3. Vertical and Horizontal Connectivity

Training includes actual equipment operating in its natural environment (real training events), simulation trainers operating in a virtual environment (virtual training), and computer-based training (constructive systems). These components can be combined in a number of ways to create many different synthetic environments for training that range from a level of small group engagement to strategic training involving a joint task force. It is also possible to nest various levels of training within higher levels. Thus a small group may be engaged in a set of tasks which is occurring as a direct result of the actions taken by the joint task force leader and the results of that engagement will directly influence their subsequent planning and decisions. While it is possible to link a wide variety of live, virtual, and constructive training events both horizontally within a capability echelon and vertically across echelons, it is essential that we identify the training benefits for each level of participants in team training. The capability to create larger and larger scenarios with more participants does not necessarily increase the training value of DMT. It is possible to position individuals or teams in certain specialties or echelons serving as training aids for other specialties or echelons. If this is not considered during the design of training scenarios, we run the risk of alienating some participants and also reducing their specific task-critical training opportunities. Assuming that there is a valid training reason for linking various echelons of players and classes of training in mission-specific aggregate training events, still a number of unresolved technical issues (e.g, aggregation and separation of team members and communication between constructive and manned systems) as well as training issues (e.g., behavioral representation and scenario management) need to be well studied.

8.3.4. Physiological Training Issues

In real life missions, team players are usually exposed to a wide variety of psychological and physiological stressors. While technology is providing us with an ever increasing ability to replicate many of the psychological stressors, we are still severely limited in our ability to duplicate many of the physiological stressors encountered in practice. For example, consider the physiological environment in which the modern fighter pilot operates. This environment involves breathing oxygen, being cramped on a small space, experiencing a number of conflicting sensor cues, and enduring various degrees of G-stress. It is impossible to fully replicate these physiological stressors in an affordable simulator. Unfortunately, we still

do not know the optimal mix of cognitive, procedural, psychomotor, and physiological training required developing and maintaining one's ability to successfully employ a fast, highly maneuverable fighter aircraft. Although DMT may allow trainees to receive better training in certain tasks, it may also provide poorer training in those tasks that are closely tied to the one's ability to quickly recognize an opportunity and aggressively maneuver the equipment to secure a tactical advantage. These are critical research issues that need significant attention.

Table 7. Critical Questions in Developing Training Systems

- What is the role of the instructor(s) in the training process?
- How will multiple instructors at different locations monitor and control training?
- What tools are needed for scenario development, modification, and management?
- What kind of performance feedback is required and how will it be delivered?
- What kind of training will instructors need?
- How does the technical support staff (e.g., network technicians) communicate critical status information to the instructors?
- How are individual entities at various sites initialized and monitored for both technical and mission related performance?
- How are automated performance measurement systems enabled?
- How digital or non-digital data that may not be readily analyzed by automated performance measures (e.g., communications) be used to describe team performance?
- When and how will mission planning and post-operative analyses be conducted?
- How much intervention will be allowed once a scenario starts?
- Will the instructors be allowed to freeze and replay training events?
- Which teams need to interact with one another and how will mission planning and post-operative analyses among multiple teams be conducted?
- How does one ensure a "level playing field" within a homogenous virtual platform training network?

9. Conclusion

The tremendous growth in computer and communication technologies provides unparalleled opportunities to create synthetic environments that will revolutionize training. Today we are witnessing the first attempts to integrate this technology within Air Force training systems as part of the DMT program. Initial demonstrations of DMT have been extremely encouraging. Although the DMT technologies are indeed quite impressive, they represent only a fraction of the big picture that emerges in the training landscape. Equally important are the soft technologies (e.g., human factors, education, and applied cognitive science) that are essential for the development, implementation, and assessment of training. These soft technologies are critical to the design and development of training delivery systems as well as training evaluation. While DMT has made significant technical progress, there still are a number of human-centered challenges that must be addressed in order to deliver effective and efficient training.

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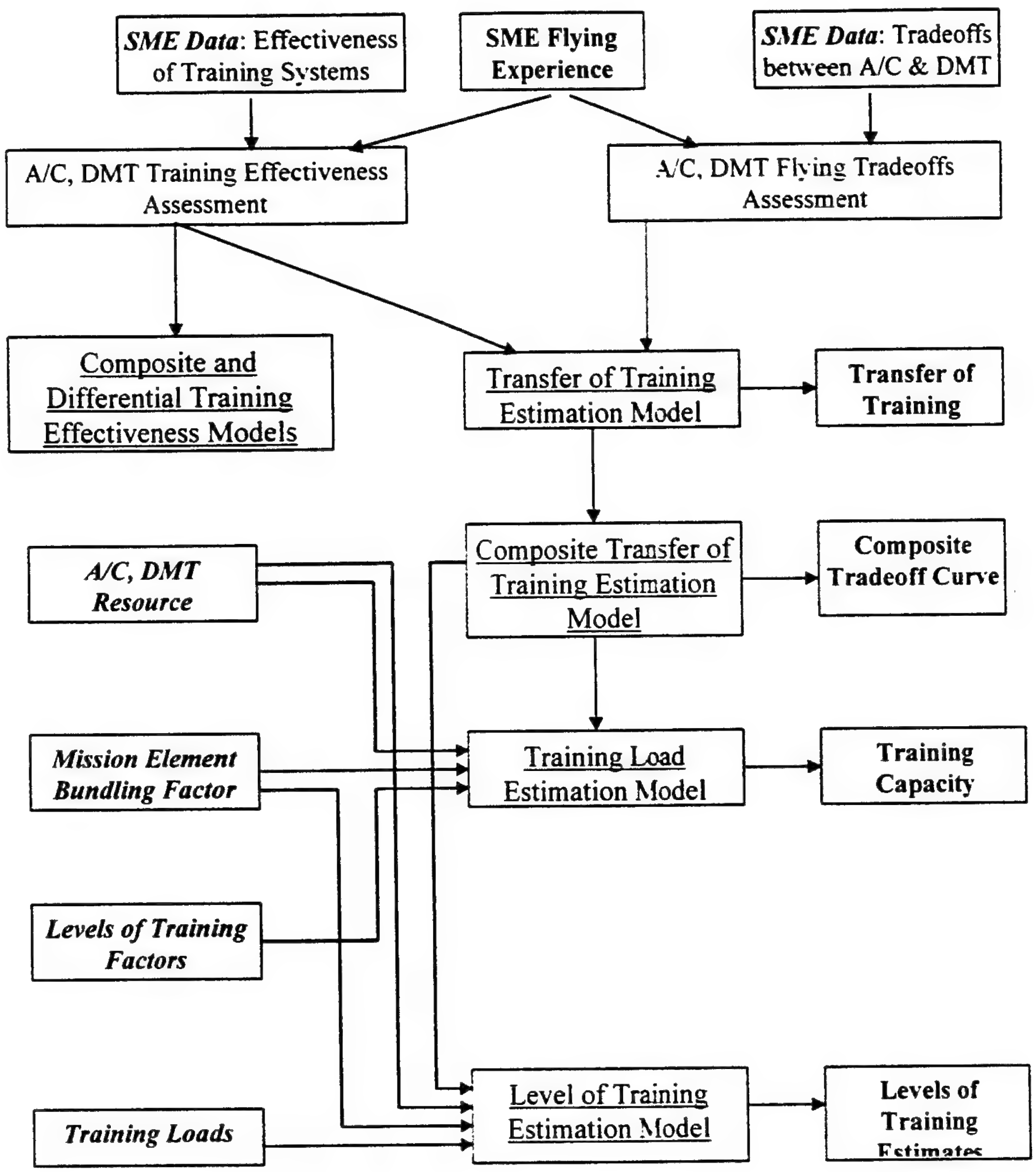


Figure 2. TRAINING EFFECTIVENESS AND A/C-DMT TRADEOFF ASSESSMENT SYSTEM

APPENDIX:[redacted]

COST - EFFECTIVENESS MODELING OF F16 DMT SYSTEMS

R. Ramesh, Ph.D.
Professor
School of Management
SUNY at Buffalo
Buffalo, NY 14260
Ph: (716)645-3258
Fax: (716)645-6117
Email: rramesh@acsu.buffalo.edu

Reference:

R. Ramesh and D. H. Andrews, "Aircraft and DMT: Modeling and Analysis of Trainining Effectiveness, Flight Tradeoffs and Resource Allocations," ARL Research Report, 1998.

SYSTEM OBJECTIVES:

The objectives of this spreadsheet modeling and analysis system are:

1. **Perform Aircraft - DMT flying time tradeoff analysis**
2. **Perform training capacity analysis for joint aircraft - DMT training**
3. **Perform a high level cost analysis of DMT configurations**

MAJOR INFORMATION SOURCES:

1. SME assessments from the Roadrunner'98 exercises
2. Inputs from SMEs at ARL (Mesa, AZ), ACC/DR, DO (Langley AFB), ASC/YW (WPAFB)
3. CF-18 Feasibility Report, ARL, Mesa, AZ, 1997
4. C-130 Cost-Effectiveness Analysis Report, ARL, Mesa, AZ, 1993
5. Moor & Andrews Report, AL-TP-1992-0023, ARL, Mesa, AZ, 1997

PLEASE GO TO THE NEXT WORKSHEET FOR MORE DETAILS ......

SYSTEM ARCHITECTURE

The system consists of the following worksheets:

Quest_1 - Quest_6 Primary SME input data from Roadrunner'98

INPUTS: Statistical data processed from the primary SME inputs

TRANSFERS: Transfer of Training Curves calculated from INPUTS worksheet

2SHIP: 2-Ship DMT parametric sensitivity analyses. This consists of:
: Analysis of task level Aircraft-DMT sortie tradeoffs
: Estimation of Aircraft/DMT sortie requirements for various tradeoffs
: Estimation of Composite Aircraft/DMT total sortie transfer function

4SHIP: 4-Ship DMT parametric sensitivity analyses. This consists of:
: Analysis of task level Aircraft-DMT sortie tradeoffs
: Estimation of Aircraft/DMT sortie requirements for various tradeoffs
: Estimation of Composite Aircraft/DMT total sortie transfer function

CAPACITY: Parametric sensitivity analyses of:
: Training capacities of a given set of Aircraft/DMT traning resources under various Aircraft/DMT sortie tradeoff configurations

TR_LEVELS: Parametric sensitivity analyses of:
: Levels of Training accomplished under:
: Given set of Aircraft/DMT training resources, and
: Given set of training loads (# of pilots to be trained)

EFFECTIVENESS: Differential transfer effectiveness curves:
: Aircraft - 2SHIP DMT
: Aircraft - 4SHIP DMT
: 4SHIP - 2SHIP DMT

ACQ_COST_NR: Record and Analysis of Nonrecurrent acquisition costs of DMT

ACQ_COST_RR: Record and Analysis of Recurrent acquisition costs of DMT

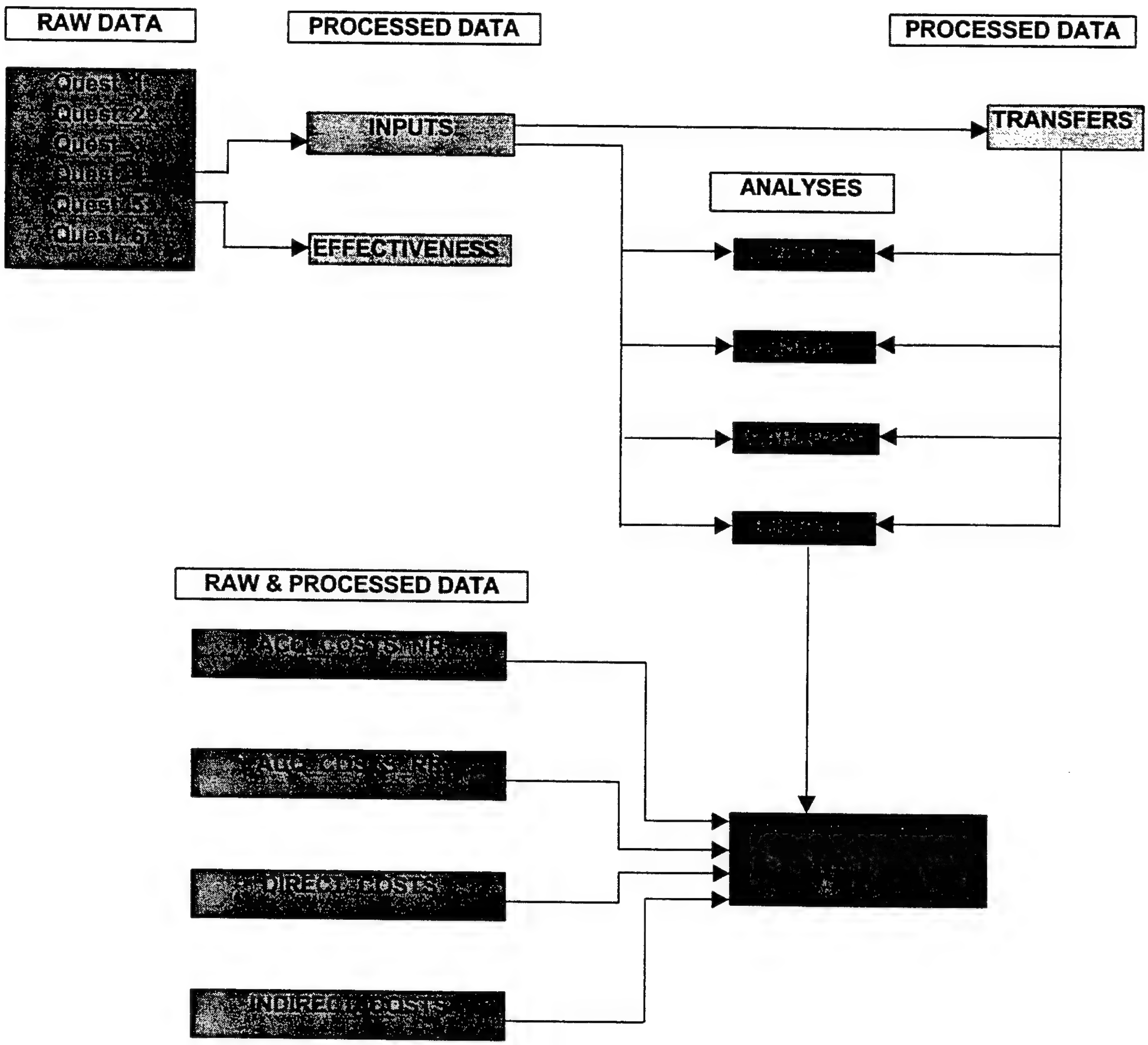
DIRECT_COSTS: Record and Analysis of Direct Operational costs of DMT

INDIRECT_COSTS: Record and Analysis of Indirect Operational costs of DMT

COST_ANALYSIS: Parametric Sensitivity Analyse of:
: Cost savings over a 30 year period due to DMT usage
: Costs associated with DMT systems over 30 years
: Net cash flow analysis over 30 years with DMT systems
: Above analyses are performed for 2-Ship & 4-Ship DMT under each Aircraft/DMT sortie tradeoff configuration, training requirements, lifetime performance of aircraft and DMT systems and constraints on available resources.

PLEASE GO TO THE NEXT WORKSHEET FOR MORE DETAILS ......

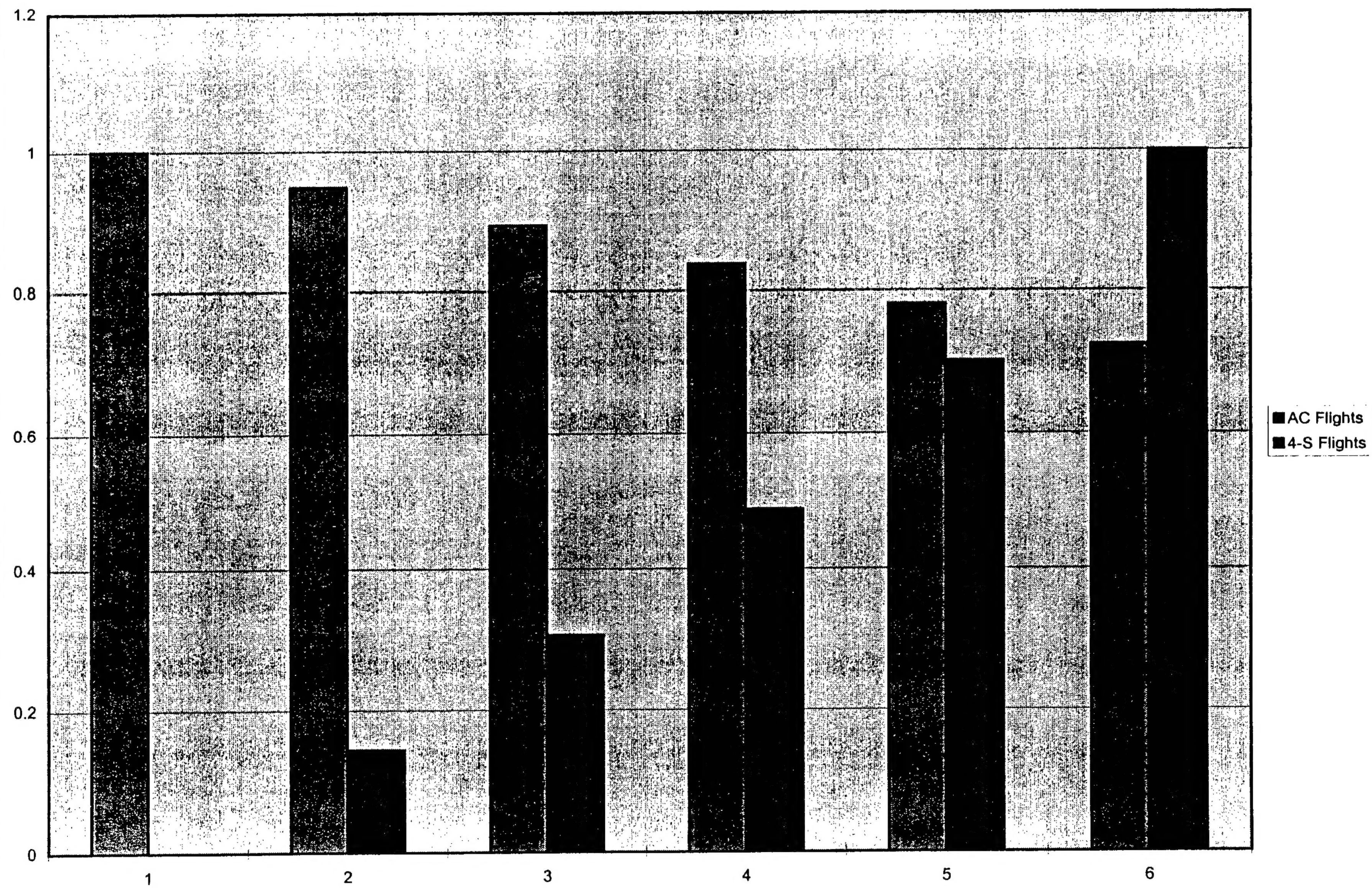
Worksheet Access Paths



YOU CAN NOW START YOUR ANALYSES.................

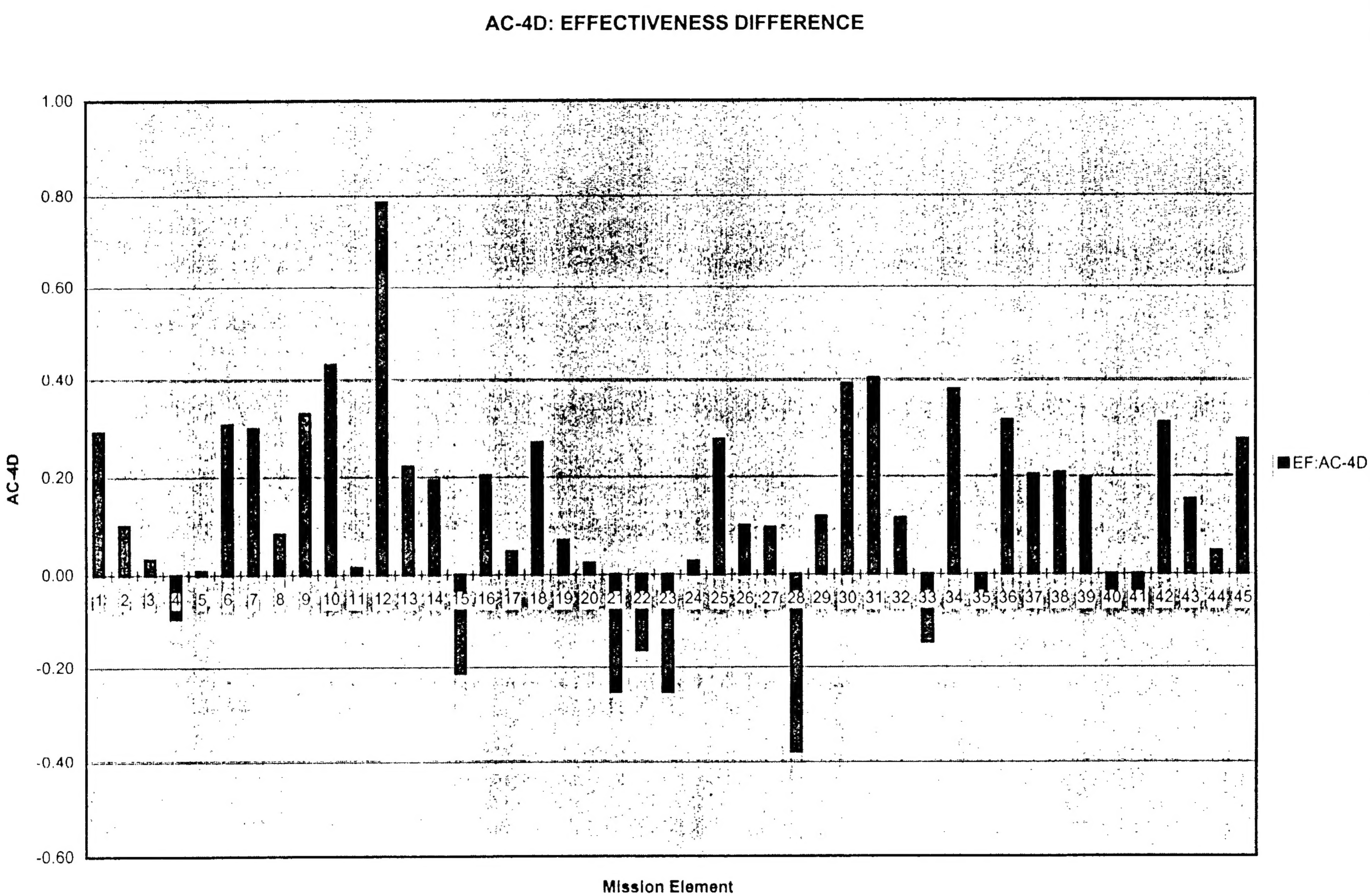
**PLEASE FOLLOW THE RECOMMENDED FLOW OF ANALYSES.
SEE FLOW CHART IN THIS WORKSHEET.**

4SHIP Chart 3



Flight Tradeoff from Aircraft to 4-ship DMT

EFFECTIVENESS Chart 8



OVERALL COST ANALYSIS

USER GUIDE

USER GUIDE

GREEN

2 - SHIP DMT ANALYSIS

INPUT DATA

Level of Practice for INX Pilots - Choose Between:	0	
Level of Practice for EXP Pilots - Choose Between:	0	
Design Life of an Aircraft (in # of Sorties)		
Cost of flying an aircraft per sortie		
Cost of an aircraft		
Number of Inexperienced Pilots to be trained		
Number of Experienced Pilots to be trained		
A/C Sorties/INX Pilot/YR (when only A/C is used)		
A/C Sorties/INX Pilot/YR (A/C & 2-ship are used)		
A/C Sorties/EXP Pilot/YR (when only A/C is used)		
A/C Sorties/EXP Pilot/YR (A/C & 2-ship are used)		
Number of Aircraft available		
Number of 2-Ship DMT Available		

ANALYSIS OF SAVINGS

Number of sortie reduction/aircraft/year
Total Number of aircraft sortie reduction/year
Original Life of an Aircraft (in # of years)
Life of an aircraft when 2-ship DMT is also used
Cost savings/YR due to A/C sortie reduction
Cost savings/YR/Aircraft due to A/C sortie reduction
Cumulative Cost Savings over A/C lifetime
Cumulative Cost Savings/Aircraft over A/C lifetime

DMT COSTS

Acquisition Cost - Nonrecurring
Acquisition Cost - Recurring
Average Recurrence Factor
Annual Direct Cost
Annual Indirect Cost

NET CASHFLOWS			
INTEREST RATE			[illegible]
	YEAR	0	17,093,530
	YEAR	1	2962375.784
	YEAR	2	2962375.784
	YEAR	3	2962375.784
	YEAR	4	2962375.784
	YEAR	5	2962375.784
	YEAR	6	2962375.784
	YEAR	7	2962375.784
	YEAR	8	2962375.784
	YEAR	9	2962375.784
	YEAR	10	2962375.784
	YEAR	11	2962375.784
	YEAR	12	2962375.784
	YEAR	13	2962375.784
	YEAR	14	2962375.784
	YEAR	15	2962375.784
	YEAR	16	2962375.784
	YEAR	17	2962375.784
	YEAR	18	2962375.784
	YEAR	19	2962375.784
	YEAR	20	2962375.784
	YEAR	21	2962375.784
	YEAR	22	2962375.784
	YEAR	23	2962375.784
	YEAR	24	2962375.784
	YEAR	25	2962375.784
	YEAR	26	2962375.784
	YEAR	27	2962375.784
	YEAR	28	2962375.784
NET PRESENT VALUE OF CASHFLOWS			[illegible]